CHAPTER 2
FOUNDATIONS AND CRAWL SPACES

SECTION I—FOUNDATIONS

2.1.1 General

The foundation of a building or structure transfers the dead and live loads of the superstructure to soil that has enough bearing capacity to support the structure in a permanent, stable position. Footings are used under foundation components, such as columns and piers, to spread concentrated loads over enough soil area to bring unit pressures within allowable limits. Foundation design is determined not only by the weight of the superstructure, but also by occupancy, use, and the load-bearing capacity of the soil at the site. Soil conditions may change over a period of time and introduce maintenance and repair problems even in initially well-designed foundations.

2.1.2 Materials and Types of Foundations

2.1.2.1 *Materials.* Materials for foundations are, in general, concrete (plain or reinforced), concrete masonry units (open or filled cells), bricks, cut stone, rock, and wood. Brick, cut stone, and rock foundations are usually found only in older structures.

2.1.2.2 *Types of Foundations.* Foundations vary from simple walls and piers with footings to very complex movement-resistant walls and slabs placed without joints. Several basic types may be used in one structure. Due to the broad variety of structures on military installations, maintenance personnel should be familiar with a variety of foundation designs used to meet many conditions. Some typical foundations follow:

a. Walls of concrete, masonry units, or brick were sometimes built without footings to support lightweight buildings on soils of high load-bearing capacity. See figure 2-1. Refer to chapter 4, section 4.3 for discussion of concrete walls.

b. A separate footing may be used under each column, or a footing may be extended continuously (spread) under a number of columns or a wall. Spread footings are required where imposed loads are great or the soil at the site has a low bearing value. Footings are commonly constructed of concrete, although brick and stone may be found in older construction. Concrete is used plain in mass or reinforced by steel rods, depending on bearing loads. See figure 2-2.

c. Spread footings and walls or piers of reinforced concrete poured integrally are used for heavy structures, and where heavy lateral forces are exerted on one side of the wall. Examples are retaining walls, deep basements, and swimming pools.

d. Spread footings and grade beams of reinforced concrete may be used in large structures without basements. See figure 2-3. The columns transmit the heavy localized loads to the substructure, and the grade beams carry the relatively light, first-story curtain wall. The spread footings are designed and built independently to support both the column loads and the grade beam. Where grade beams are above the frostline, the bottom of the beam may be V-shaped to minimize the upward thrust of frost action on the bottom surface of the beam.

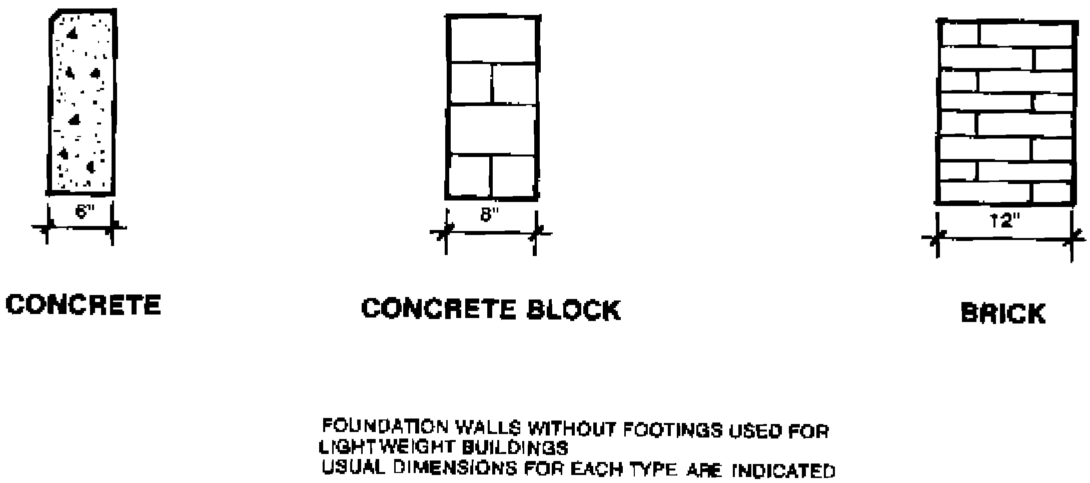
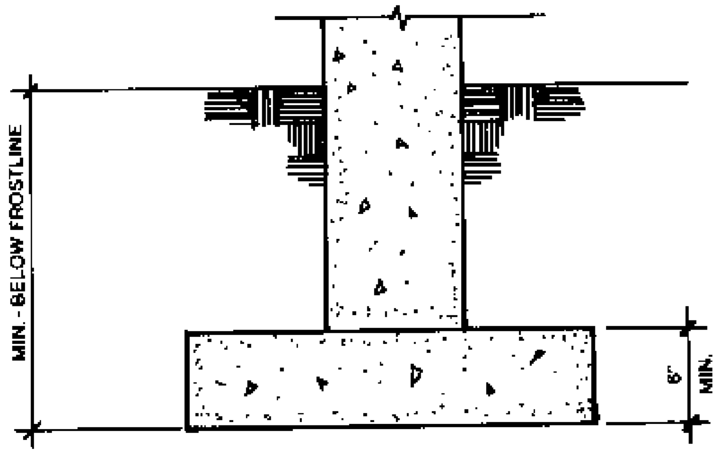
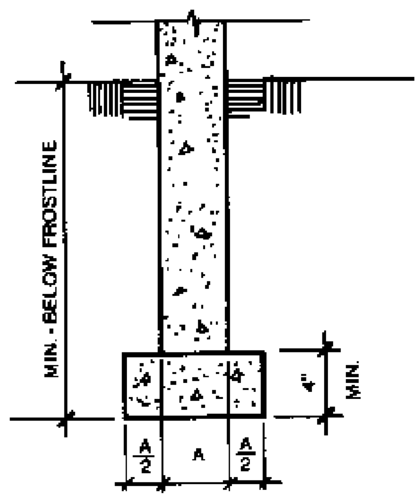


Figure 2-1. FOUNDATION—WALLS WITHOUT FOOTINGS.



FOR HEAVY WALLS



FOR LIGHT WALLS

Figure 2-2. CONCRETE FOOTINGS.

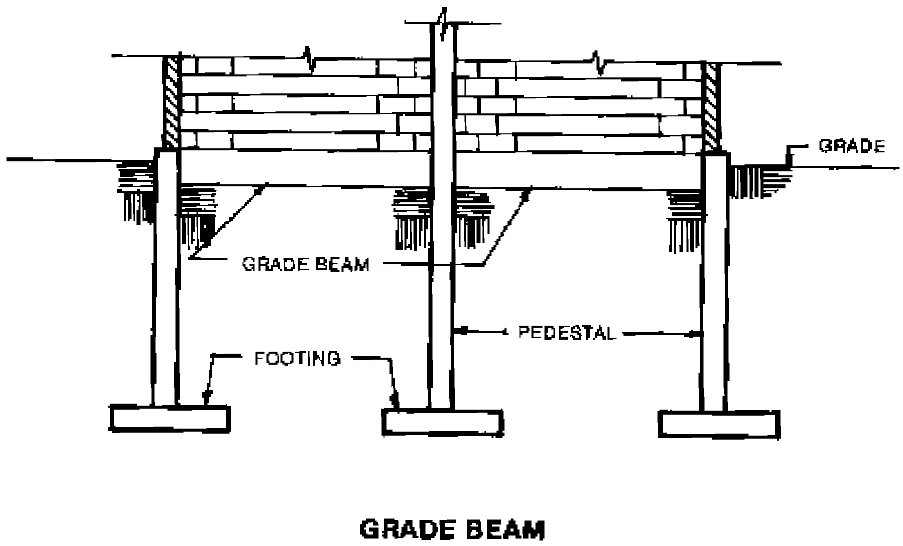


Figure 2-3. GRADE BEAM.

e. A mat foundation is one that transmits its loads to the bearing soil by a continuous slab that covers the entire area of the bottom of the structure, e.g., a floor. It is used when the low-bearing value of the Soil results in such large isolated footings that it is more logical to transmit the loads through this slab to the entire area directly under the superstructure. See figure 2-4.

f. There are cases in which it is undesirable to allow any major increase of pressure to the soil. One principle that may be utilized in such cases is that of the "floating foundation." This means that the estimated weight of the soil removed permanently in order to build the substructure must be equal or less than the dead and live loads of the structure, which is then "floating" by displacing its own weight in the low-bearing value soil. This type of foundation is usually designed for locations where deep and heavy footings or piles are impractical or uneconomical.

g. Brick step footings and walls or piers have been used mostly in old structures. New construction of brick foundations will normally be uneconomical when compared to concrete.

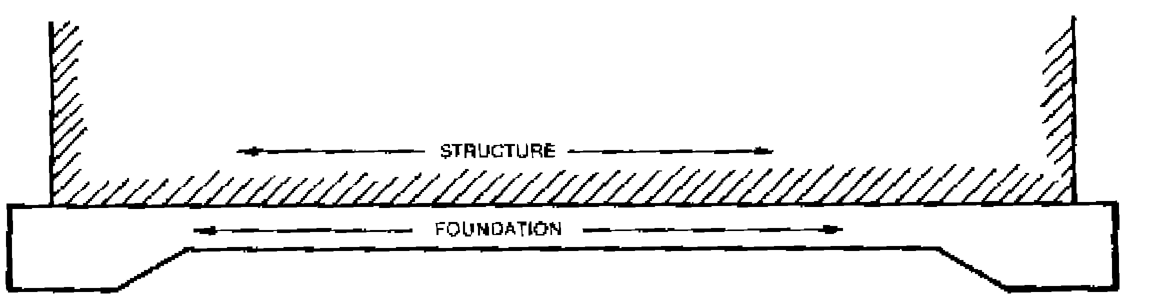


Figure 2-4. MAT FOUNDATION.

h. Cut stone foundations are usually constructed of large blocks of hard stone (similar to granite) laid with mortar or dry joints. New construction of cut stone will normally be uneconomical when compared to concrete.

i. Natural or field stone foundations are laid with mortar or dry joints. Where stone is plentiful, it can be used economically for light structures. It can also be used for retaining walls and dry walls.

j. Grill age footings have been used for light loads, where the bearing area required is not larger than the pedestal. See figure 2-5. These footings consist of several layers of beams, normally of wood or steel, with successive layers at right angles to each other and with successively deeper layers having larger beams. However, the rising cost of labor has made these footings uneconomical. Wood Grill age footings are sometimes used to support wood posts, columns, masts, poles, and light temporary structures. Wood used in substruc tures is usually pressure-treated with various types of preservatives. Such footings permanently below ground-water level may last indefinitely and require no maintenance.

k. Piles are made of steel, wood, concrete, steel and concrete, and wood with concrete. Piles are usually capped with a reinforced concrete mat or slab. See figure 2-6. Wood piles are usually treated with a preservative and should be totally [and permanently] below ground-water level.

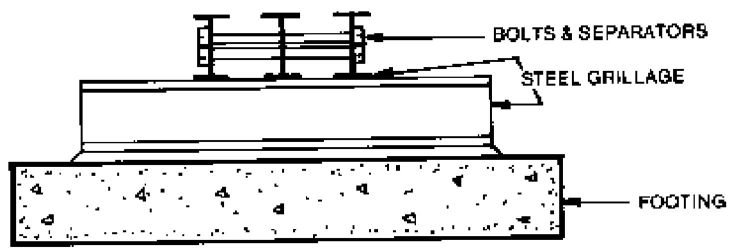
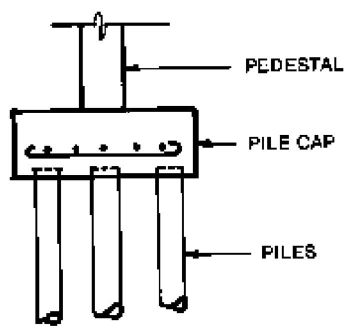


Figure 2-5. STEEL GRILLAGE FOUNDATION.



PILES MAY BE WOOD, STEEL, CONCRETE, OR COMBINATION OF MATERIALS

Figure 2-6. PILE FOUNDATION.

2.1.3 Inspection for Distress and Failure

Exposed portions of foundations should be inspected regularly. Inspections should occur more frequently where climate, soil conditions, or changes in building occupancy or structural use present special problems. Evidence of incipient foundation failure may be found during routine inspection of other structural components.

2.1.3.1 *Foundation Displacement.* Foundations should be checked regularly for proper elevation and alignment. Complete failure in foundations is rare. However, some settling or horizontal displacement may occur. See figure 2-7 and 2-8. Common causes of foundation movement include settlement and differential settlement of the soil caused by inadequate compaction of the soil or improper sizing of the footings; overloading the structure; excessive ground water which reduces the bearing capacity of soil; inadequate soil cover which fails to protect against frost heaving; and adjacent excavations that allow unprotected bearing soil to shift from under foundations to the excavated area. Severe, localized foundation displacement may show up in cracked walls, damaged framing and connections, sloping floors, sticking doors, and even leakage through a displaced roof.

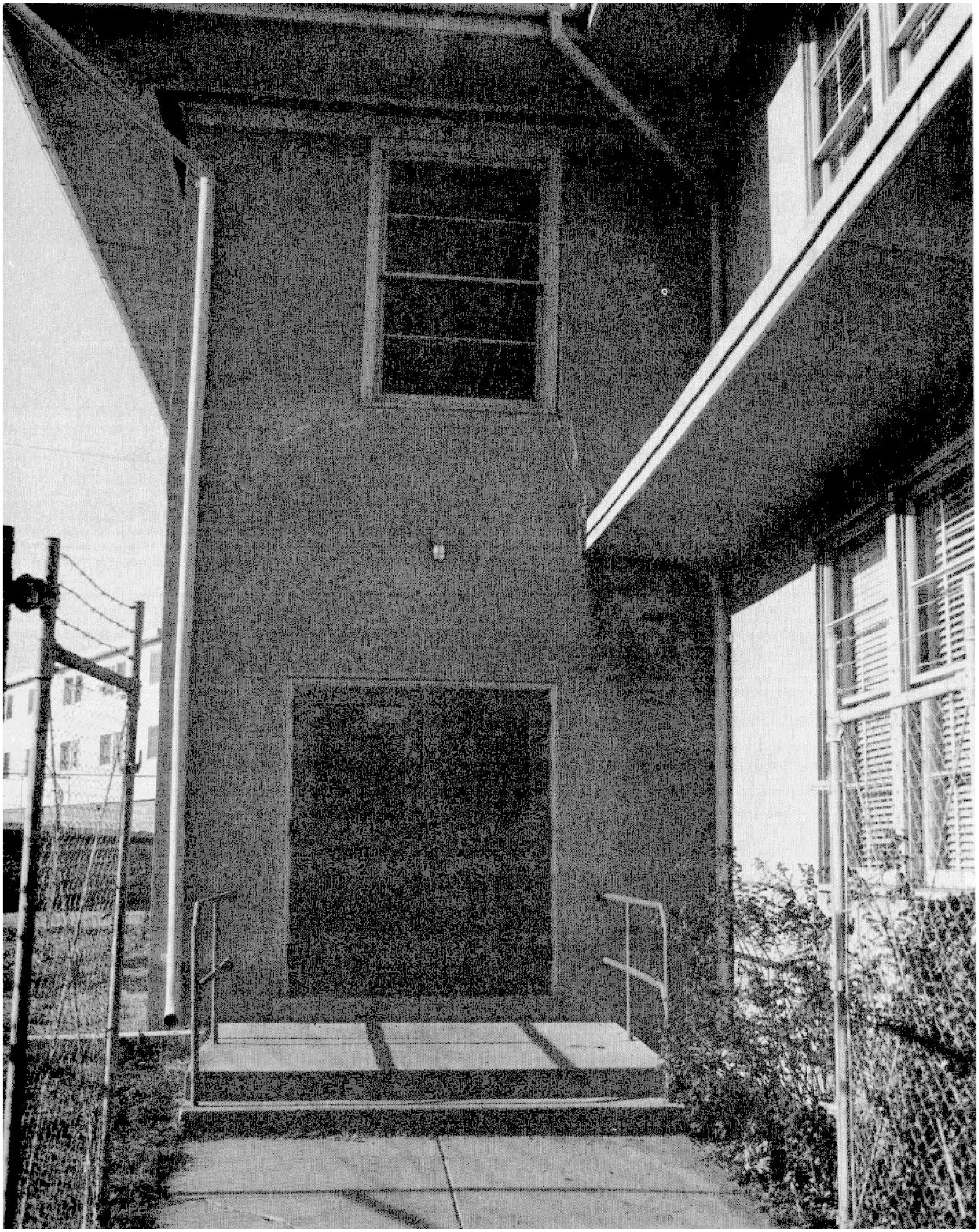


Figure 2-7. CRACKS CAUSED BY FOUNDATION SETTLEMENT—EXTERIOR.

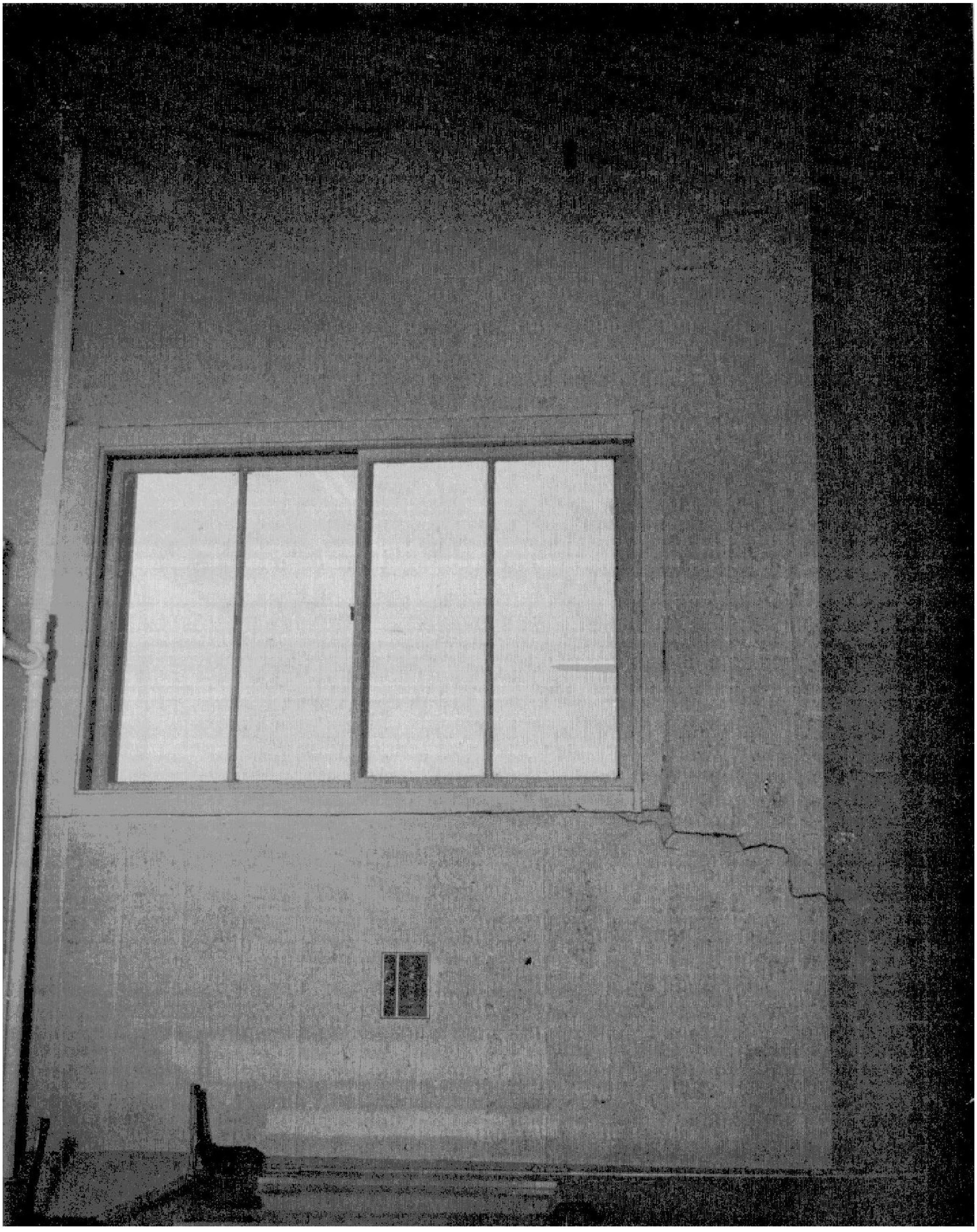


Figure 2-8. CRACKS CAUSED BY FOUNDATION SETTLEMENT—INTERIOR.

2.1.3.2 *Material Deterioration.* Foundations are subject to deterioration, whether from material or construction deficiencies or from environmental conditions. Generally, the deterioration of foundation materials can be determined only by direct observation, unless the effects are severe enough to cause foundation settling. Excessive moisture from surface or subsurface sources is a major cause of timber deterioration, providing the necessary condition for wood decay and encouraging insect infestation. Improperly seasoned wood is subject to cracking, splitting, and deflection. Concrete and masonry are subject to cracking, spalling, and settling, particularly under adverse ground and climatic conditions. Steel and other ferrous metals are subject to corrosion in the presence of moisture and sometimes by contact with acid-bearing soils. Signs of corrosion are darkening of the metal, rusting, and pitting.

2.1.4 Soil Investigation

In all cases of serious foundation settlement, an investigation of the bearing soil should be made as a basis for corrective action. The stability of soils is derived from their shearing strength (or resistance), which may change with ground conditions at the site. Clay-bearing values, for example, vary with moisture content. A foundation on a clay site that has been laid on the basis of local standards for bearing value may settle when the moisture of the clay increases (and therefore loses shearing strength), when dewatering operations are undertaken in the area, or when an adjacent, deeper excavation drains moisture from the foundation-bearing clay. Clay also loses strength when molded or worked. Frost action is similar in effect to working the clay. Other soil types are subject to change in bearing value or characteristics. Silty soils have greater capillary action than sand and, under severe winter conditions, may absorb enough water to form ice lenses under the footings. The most exposed side of a structure will have the greatest frost action. When the ice thaws, the soil is oversaturated and incapable of supporting a load. The specific maintenance measures given in the following paragraphs provide a partial listing of conditions to be noted during an inspection.

SECTION II—CONCRETE SLABS ON GRADE

2.2.1 General

Concrete slabs on grade may transmit dead and live loads directly to the subgrade independent of the remainder of the structure (floating slab), or they may be structurally integrated with the foundation walls, piers, columns and footings (structural slab), so as to become a part of the structural foundation. Floor slabs on grade are normally separated structurally from the rest of the building. See figure 2-9.

2.2.2 Types of Concrete Slabs on Grade

Typically, concrete slabs on grade consist of three principal types:

2.2.2.1 Plain, unreinforced, flat slabs carrying uniformly distributed light loads usually not more than 100 pounds per square foot (lb/ft^2).

2.2.2.2 Welded wire-mesh, reinforced flat slabs carrying uniformly distributed medium loads, usually not more than 500 lb/ft^2.

2.2.2.3 Deformed steel bar reinforcing in flat slabs carrying heavy, uniformly distributed, or concentrated loads.

2.2.3 Typical Concrete Slab Construction

2.2.3.1 *Subgrade.* Remove all sod and decomposable material; backfill as required; compact and shape the surface. Backfill should be of uniform character, free from large lumps, stones, frozen chunks, or material that will rot. The material selected for backfill should provide a density equal to the natural density of the surrounding soil. Better results and greater densities can be attained by using the backfill material at its optimum moisture content. In large jobs, or particularly important slabs, the optimum moisture content should be determined by laboratory analysis; however, a rough idea of the proper moisture content for ordinary soils (except very sandy soil) can be determined by forming a ball of the soil by hand. Proper moisture content will result in a ball that will hold its shape, but not be plastic or muddy when squeezed. Trenches for pipes, footings, utility lines, etc., must be backfilled in layers not exceeding 6 inches in thickness and each layer tamped so that the backfill will be as dense and strong as the surrounding subgrade.

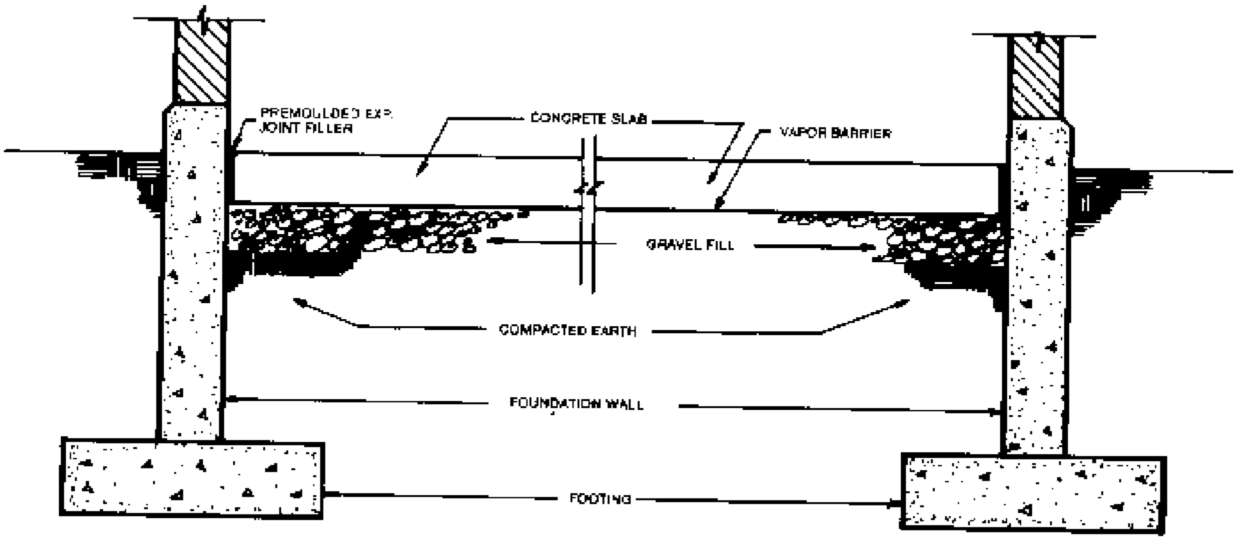


Figure 2-9. FLOOR SLABS ON GRADE.

2.2.3.2 *Gravel Fill.* On the subgrade, place a 4- to 6-inch layer of granular fill and cover with a vapor barrier.

2.2.3.3 *Reinforcement.* Reinforcement in slabs on grade serves primarily to hold the edges of cracks tightly closed and also to distribute loads that contribute to the load-carrying capacity. If control joints are spaced as recommended hereinafter, reinforcement may not be necessary. However, it is preferable to use a nominal amount of reinforcement where the uniformity and strength of the subgrade may be questionable. Such steel supplied should be small bars or welded-wire fabric installed at middepth of slab.

2.2.3.4 *Placement of Concrete.* Concrete for structural slabs should be made with hard, well-graded aggregates and should contain not more than the number of gallons of water specified for each sack of cement. It should be a workable mix which can be placed without honeycombing or permitting excess water to accumulate on the surface. The concrete shall be placed as near to the final resting place as possible, thoroughly compacted by vibrating or tamping and spading, and screeded to proper grade for drainage. The minimum practical thickness for a light-duty slab is 4 inches; for medium-duty, 6 inches; for heavy-duty, 8 inches or more.

2.2.3.5 *Joints.* Joints are required in concrete slabs to permit expansion and contraction of the concrete due to temperature and moisture changes, to relieve warping and curling stresses which result from temperature and moisture gradients within the slab, to minimize uncontrolled cracking caused by frost action, and as a construction expedient to separate the areas of concrete placed at different times. There are three general types of joints used in concrete slabs: contraction, expansion, and construction. See figures 2-10 and 2-11.

a. Contraction Joints. The initial shrinkage of concrete is often greater than subsequent movements of the slab by moisture or temperature

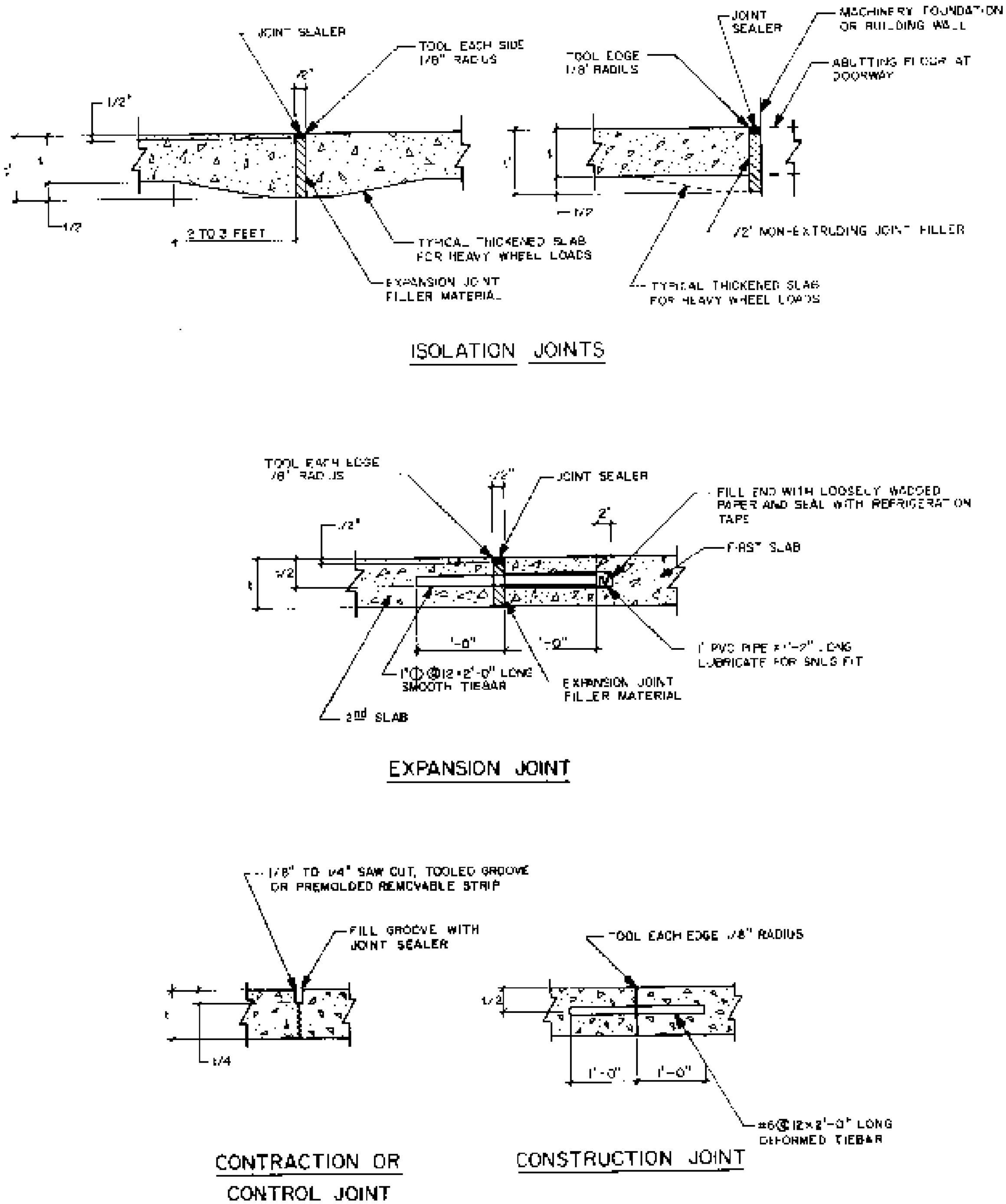


Figure 2-10. BUTT JOINTS.

changes. Under normal conditions, joints are placed approximately 15 to 20 feet apart, or on each column line, whichever is less.

b. Expansion Joints. Expansion joints are to be installed at walls, columns, and machinery pads, and at 60- to 90-foot intervals. The width of joints varies from ¼ to ¾ inch, depending on the joint spacing and the expected temperature range. Expansion joints at walls, columns, and machinery pads should be designed to allow differential settlement of the floors and footings. Expansion joints will serve as contraction joints, but contraction joints cannot serve as expansion joints.

c. Construction Joint& Construction joints are provided to separate areas of concrete placed at different times. Insofar as practicable, these joints will be installed at the location of a planned joint.

2.2.3.6 *Joint Filler Material.* Joints are, with a few exceptions, lines of complete separations of the slab. In order to keep the joint clear and free to move, the joint is filled with an expansible material, and may or may not have water seals. The water seals also expand and contract with the movement of the slab. Filler material is generally of two major types:

a. Hot or cold asphalt, tar, or other thermoplastic or bituminous compounds, poured, placed or gunned into the joint. Cold joint-sealing compounds, applied under pressure, are more satisfactory for narrow joints, **c** to $^{3}/_{16}$ inch wide, which cannot be filled by other methods.

b. Premolded joint filler strips, manufactured in a wide variety of thicknesses, depths, and lengths, may be composed of wood, fiber, cork, spunglass, rubber composition, felt and other compressible or expansible materials, usually with an asphalt or tar binder (see ASTM D-1751 and D-1752). The filler strip is equal to the width of the joint opening, and a maximum of ¾ inch below the surface of the slab. After the concrete has set, the joint is filled to slab level with poured asphalt (see ASTM D-1850 and Federal Specification SS-S-1401) or other thermoplastic compounds. In areas of expected heavy spillage of diesel fuel, jet fuel, aviation gasoline or lubricants, a jet-resistant sealant conforming with Federal Specification SS-S-1614 or SS-S-200D will be used.

2.2.3.7 *New Joints in Existing Slabs.* Where new joints have to be made in existing slabs, extreme care will be used throughout the operation. The concrete slab will be broken using drills, chip hammers or saws, depending on the extent of the work and the availability of equipment. Joints will be cut cleanly to the desired dimensions. All dust, dirt and other debris will be removed from the joint before installation of joint material.

2.2.4 Joint Maintenance

As a general rule, joints in slabs on grades need little or no maintenance. If the joint is in good condition, it should be left undisturbed. The major maintenance is required by the expansion joints where the constant movement (working) of the slab, due to the effects of temperature and moisture, deteriorate the joint material. If maintenance is to be performed, all joint material should be removed. The joint should be swept clean of all debris, and the edges of the joint trimmed to present a clean surface. New joint material of the proper thickness and depth should be installed. New or better joint material may be substituted for the original material if economically feasible.

2.2.5 Special Considerations

Utility ducts and drainage trenches in slabs on grades may be poured integrally or separately in new construction, or built into existing slabs.

2.2.5.1 *Ducts and Trenches.* Size and location of utility ducts and trenches will be established, in conformance with the construction drawings. Particular care will be taken to see that ducts are thoroughly waterproofed. Drains will be provided to carry off any accumulation of water. These drains will be separate from all other drains leading into a main storm sewer.

2.2.5.2 *Trenches.* Floor drainage trenches will have metal-grating covers and be placed to intercept surface drainage at hangar doors, vehicular entrances, and at other locations as required.

2.2.6 Exterior Slabs on Grade

Exterior slabs on grade (i.e., vehicular entrance ramps, platforms at pedestrian entrances, transformer or equipment pads) are similar in design and construction to interior slabs on grade except that they must be supported and drained to resist frost action, surface water, ice, snow, and other conditions of the elements. Exterior slabs may be attached to, or be independent from, structures. Brackets, dowels, shelves, and other types of piers may be used for support, or exterior slabs may be poured integrally with the structure foundation to which they are attached. Exterior slabs to be poured independently will reply on a compacted and confined selected fill of crushed stone, gravel, sand, or cinders. In certain locales, due to subsurface water and frost conditions, the fill bed must have adequate drainage to prevent heaving and cracking. This drain may be connected to or be a part of foundation drains.

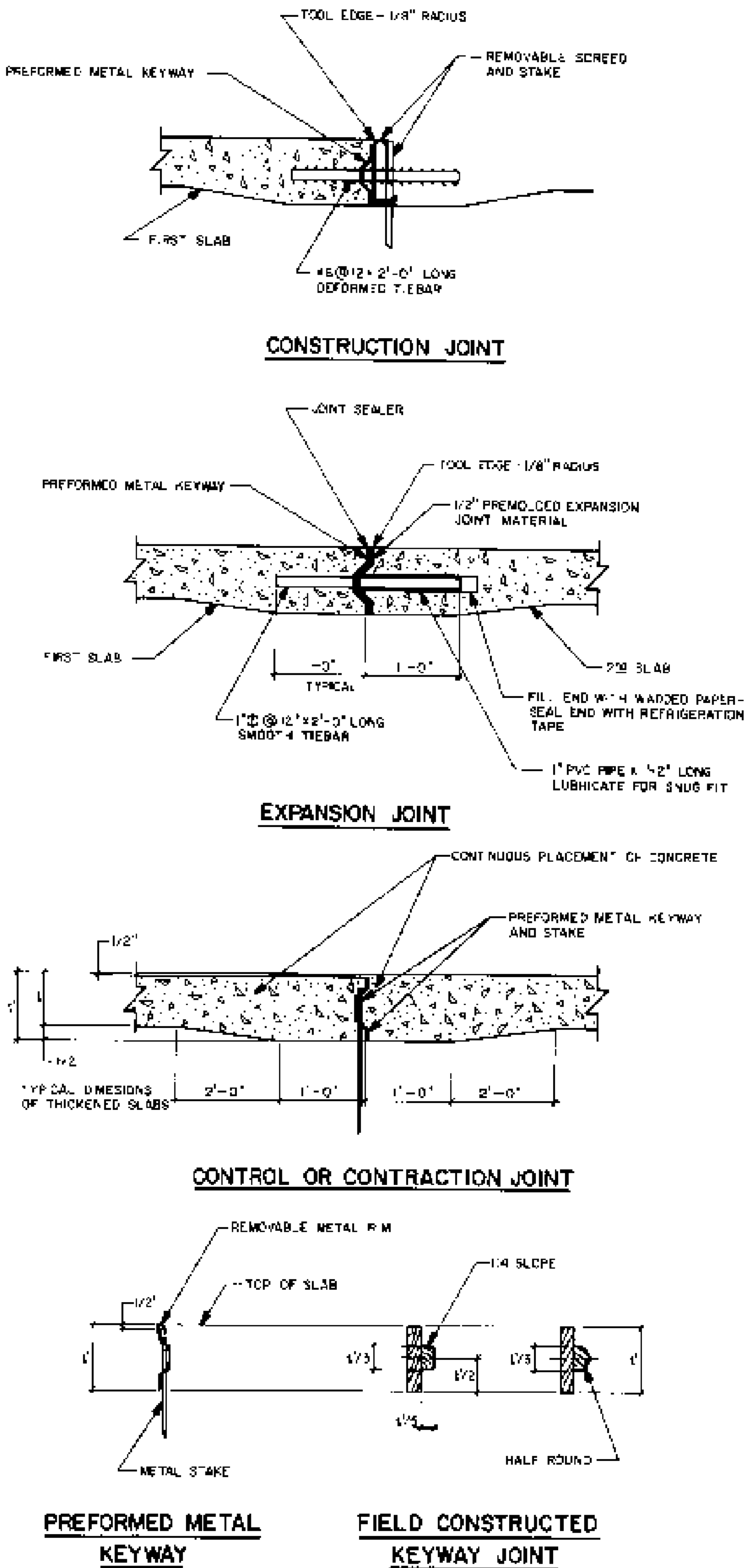


Figure 2-11. KEYWAY JOINTS.

2.2.7 Water Seals

Water seals in joints in concrete slabs on grade are usually of copper, other nonferrous metals, rubber compounds or plastic, and are used in conjunction with a mastic material. There are many types and designs, some commercially produced under patents, and others shop-fabricated from detailed designs. Because water seals are of a permanent nature, they require little maintenance. However, failure usually requires complete replacement of the affected section. These joints are used where absolute water tightness is required against a hydrostatic head, such as in swimming pools.

2.2.8 Bonding New Concrete to Existing Concrete

Proper bond of new concrete or mortar to existing concrete surfaces is important in producing durable structures. Lack of bond can result in leakage at joints, unsightly incrustations, and failure of structures. Other methods of bonding are discussed in detail under paragraph 2.2.9., Cement-Mortar Concrete Inlay, and paragraph 2.2.10., Epoxy-Resin Grouts, Mortars and Concretes.

2.2.8.1 *Making Construction Joints.* Where construction joints occur, and are not intended to be expansion or contraction points, the surface of the concrete, while still soft, should be swept with a stiff broom or scraped to remove laitance (an accumulation of fine particles on the surface) and roughen the surface. The surface should be left with some coarse aggregate projecting. Before placing the next lift of concrete, the surface should be free of loose particles and debris. Where laitance is not removed before hardening, it must be chipped away until sound concrete is revealed.

2.2.8.2 *Treatment of Bonding Surface.* The bonding surface should be kept constantly wet for at least 1 hour before placing new concrete. Time should be allowed for surface wetness to disappear just before placing new material. The surface will then be damp but slightly absorptive. A layer of concrete containing only one-half the amount of coarse aggregate should be deposited against the hardened concrete to a thickness of at least 2 inches. This is followed by the regular mix, which would be carefully vibrated to prevent honeycombing. Good results can also be secured by saturating the hardened concrete, then spreading a thin layer of dry portland cement about $^{1}/_{16}$ inch thick over the surface. This should be broomed into the surface and spread uniformly, then left undisturbed to absorb moisture from the base. When it becomes tacky, the new concrete should be placed immediately.

2.2.9 Cement-Mortar Concrete Inlay

When concrete slabs become rutted, spoiled or broken, the entire floor should be replaced or resurfaced. In some cases the repair may be limited to the damaged area. A cement-mortar concrete inlay is the usual method of repair. For a detailed discussion of floor repairs and resurfacing, see chapter 6, section 6.3.

2.2.9.1 *Concrete Specifications.* The materials to be used to make the concrete mix will be specified by a qualified engineer. This specification will include the quality of the cement (see ASTM C-94), the gradation of the coarse and fine aggregate, the proportions of the concrete mix, and any additives that might be required. Adjustments of the proportions to make a workable mix will be under the control of a qualified supervisor.

2.2.9.2 *Mixing and Placing* Mix each batch mechanically 2 to 3 minutes, place material on slab, and vibrate, roll, or tamp it firmly into place. A grill-type tamp can be made by nailing strips about ½ inch wide and ½ inch deep, spaced about **d** inch apart, to the face of an ordinary tamp. Screed material to designated levels and float surfaces with wood, or preferably a power float. Let stand for 30 to 45 minutes or until pressure from finger ceases to make a dent, then steel-trowel to final finish. Do not sprinkle water on it in finishing. Be careful that finishing does not bring any excess fines to the top. Maintain existing expansion joints.

2.2.9.3 *Curing* Place a suitable covering material (plastic, burlap) or curing compound (spray paint) on the new surface as soon as it has set enough to not be marred.

2.2.9.4 *Reuse of Floor.* If high early-strength cement is used, the floor can be used after *3* days unless temperature has been below 45°F (7.3°C). In that case allow 5 days. Where standard portland cement is used, do not use the floor for traffic loads for 7 days after installation.

2.2.10 Epoxy-Resin Grouts, Mortars and Concretes

Three types of epoxy-resin bonding systems are available for application to portland cement concrete and are distinguished in ASTM C-881, Epoxy-Resin-Base Bonding Systems for Concrete. Type I is for use in bonding hardened concrete, steel, wood, brick, and other materials to hardened concrete (see ACI 503.1). Type II is for use in bonding freshly mixed concrete to hardened concrete (see ACI 503.2). Type III is for use in producing skid resistant surfaces on hardened concrete or as a binder in epoxy mortars or epoxy concretes (see ACI 503.3 and 503.4). For each type of system, viscosity grade, temperature class, and color will be dictated by job requirements as outlined in ASTM C-88 1-78.

2.2.10.1 *General.* Approved epoxy-resin systems provide binding agents particularly suitable for use in the type of work where a high degree of bond in a short period of time is needed. The exceptionally high strengths obtainable in a very short curing time usually permit regular traffic on the slabs within 24 to 48 hours after the repair, depending on temperature conditions. The epoxy systems specified react most favorably when temperatures are in the range of 70° to 100°F (21° to 37.8°C), but satisfactory results can be obtained at temperatures as low as 40°F (4.5°C) if proper conditions are provided. The slab repairs with epoxy materials generally should not be initiated unless the air and slab temperatures are above 40°F and rising.

2.2.10.2 *Approved Epoxy Materials.* Use of epoxy-resin systems in concrete slab repair have been developed and numerous products for this purpose have been marketed under a variety of trade names. In selecting the materials for the work, uniformity is required for obtaining consistently satisfactory results. Therefore, the use of Federal specifications in obtaining or specifying epoxy-resin materials for the subject usages is mandatory. The following issue was current during the preparation of this manual: Federal Specification MMM-A-001993, "Adhesive Epoxy, Flexible, Filled (for Binding, Sealing, and Grouting)." This specification provides for two types of materials according to temperature conditions: type I is for use when slabs, materials, and atmospheric temperatures are between 68° and 104°F (20° and 40°C), and type II is for use when these temperatures are between 40° and 68°F (4.5° to 20°C). The principal difference between "binder" material and "grout" material is that grout contains an inert mineral filler and a thixotropic or jelling agent; the reactive constituents in both materials are identical.

2.2.10.3 *Applications.* The general applications or intended usages of the materials furnished under the Federal specifications are as follows:

a. Grout. The grout furnished under Federal specification MMM-A-001993 may be used for cementing dowels in preformed holes, as a bonding agent for hardened portland cement concrete, and for grouting the cracks in pavement.

b. Binder. The binder furnished under Federal Specification MMM-A-001993 may be used for repairing spalls with epoxy concretes or mortars, and for filling saw kerfs with epoxy mortars where random cracking has occurred.

2.2.10.4 *Effective Temperatures and Conditioning.* Temperature limitations of the type I and type II grout and the type I and type II binder are mandatory and are repeated here for emphasis: type I is for use when slab, materials, and atmospheric temperatures are between 68° and 104°F (20° and 40°C); type II is for use when pavements, materials, and atmospheric temperatures are between 40° and 68°F (4.5° and 20°C).

a. Slabs. If slabs and atmospheric temperatures are less than 70°F (21°C) but not below 50°F (10°C), satisfactory repairs can be obtained without creating an artificial environment, provided the slightly increased cure-out or hardening period required can be tolerated. Further, if the climatic season is such that the pavement becomes hot, with air temperatures above 90°F (32.2°C) and slab surface temperatures possibly plus 120°F (48.9°C), scheduling of repairs should be in the early morning hours, or the areas should be protected from direct sunlight prior to initiating repair operations. When slab temperatures are less than 50°F, a battery of infrared heat lamps, or another suitable heat source, should be placed over the area to be repaired for a period of about 3 hours prior to placement operations. Gentle winds can make the heat lamps ineffective; therefore, temporary windbreaks should be used as necessary. Raising the slab temperature reduces the heat loss into the slab and permits a desirable moderate heat buildup from the exothermic reaction occurring with the combining of the two components of the epoxy system. Although an entirely satisfactory repair can be obtained if this moderate heat buildup does not occur, it may prolong a satisfactory cure-out or hardening and thereby delay reopening to use. Similarly, the cure-out or hardening period for epoxy concretes and mortars can be accelerated during cool weather by the use of heated enclosures over the repaired area. The means of attaining the desired air temperature in the enclosure must be such as to avoid localized heating of hotspots since these may cause bubbling of the liquid epoxies and also induce cracking. The safest method is to provide circulating air with added precautions to insure surface temperatures in the repaired areas of not more than 100°F (37.8°C) during the hardening stage.

b. Conditioning of Aggregates. In the preparation of epoxy concretes and mortars it is desirable that aggregates be reasonably dry and conditioned to a temperature of 70° to 85°F (21° to 29.5°C). When the aggregates are cold, two adverse conditions are created. First, on addition of the epoxy material, the viscosity will be increased with decreased wetting ability; second, low temperatures of the final mixture will be conducive to a reduced hardening rate. If the aggregates are too hot, the epoxy-curing agent reaction will be accelerated, which could make placement and finishing difficult and possibly cause cracking.

c. Conditioning of Epoxy System Components. The viscosity of the two components of the epoxy system increases greatly at temperatures below 70°F prior to mixing with a mechancial stirring device. Although adequate uniformity of the mixture might be obtained at lower temperatures by a prolonged mixing time when epoxy concretes or mortars are being prepared, this could result in overly "rich" mixtures due to the reduced wetting capability.

d. "Triggering" Curing Chemical Reaction. To expedite resumption of traffic over a repaired area under low slab and atmospheric temperature conditions, it is possible to appreciably accelerate the early hardening rate of the epoxy binders. This may be accomplished by scalping off the coarser fractions (15 to 25 percent of the total) of the aggregate and heating this portion of the aggregate to about 125° to 150°F (51.7° to 65.6°C). In the preparation of aggregate-epoxy admixtures, the balance of the aggregate is added to the two previously mixed components of the epoxy system. This should give a comparatively rich epoxy concrete or mortar mixture to allow for the addition of the heated aggregates. Immediately prior to placement, the heated scalped portion is added with particular attention to obtaining uniform distribution.

2.2.10.5 *Concretes-Aggregates for Epoxy Concretes and Mortars.*

a. Concretes. The aggregates used for epoxy concretes should be' clean, dry, washed gravel or crushed stone of a **d** or ½-inch maximum size, uniformly graded from coarse to fine, and of the same quality used for portland cement concrete and bituminous mixtures. Fine aggregate and coarse aggregate of indicated sizes meeting the requirements of the ASTM C-33, "Concrete Aggregates," should be specified for epoxy concrete mixtures.

b. Mortars. The aggregate used for epoxy mortars should generally conform to the requirements of the ASTM C-144, "Aggregates for Masonry Mortar." The aggregate should be uniformly graded from coarse to fine, and it is desirable that the materials passing the No.100 sieve be held to a minimum. The permissible maximum size selected will depend on the intended usage of the mortar. For example, in the filling of saw kerfs the normal width of the cut would necessitate using an aggregate with 100 percent passing the No. 8 sieve. In general, for both epoxy concrete and mortar the maximum-sized aggregate should not exceed one-fourth the thickness of the layer being placed or the width of the opening being filled.

2.2.10.6 *Sampling and Testing Epoxy Resin Systems.* All epoxy-resin materials proposed for use must be tested for compliance with the requirements of the Federal Specification MMM-A-001993. The manufacturer's certificates of compliance with the requirements should not be accepted in lieu of tests. The samples required and the minimum quantities necessary for the tests for each manufacturer's lot or batch of materials to be shipped, or retained for use by the Government, or on Government contracts, are stated in section 4 of Federal Specification MMM A-001993.

2.2.10.7 *Trial Batches—Epoxy Mortars and Concretes.* Since variations in aggregate grading and particle shape may affect the proportions required to obtain an economical mixture that has satisfactory placing and finishing characteristics, small laboratory trial batches are desirable prior to field placement operations. Essentially, the same principles which apply for materials produced onsite, such as hot-mix asphaltic concrete and portland cement concrete, will govern. In preparing trial batches the quantity of the cement concrete will govern. In preparing trial batches the quantity of the epoxy binder to which the aggregate is added should be not less than 300 grams. The epoxy-resin binder normally will be a mixture of two components (2 parts epoxy resin and 1 part polysulfide plus curing agent). However, material shipping containers should always be checked for deviations from specified proportions. A suitable capacity metal or polyethylene container having a hemispherical bottom should be used as the mixing vessel. The polysulfide-curing agent component should be added gradually to the epoxy-resin component with constant stirring, and the stirring continued until a uniform mixture is obtained. The rate of stirring should be such that the entrained air is at a minimum. Handmixing is usually unsatisfactory and a power-driven (air- or spark-proof), propeller-type blade should be used. Epoxy concrete proportions by weight may vary from 6 to 10 parts aggregate to 1 part epoxy binder. Aggregate proportions of epoxy concrete normally will consist of about 2 parts fine aggregate to 1 part coarse aggregate by weight. The epoxy mortars may vary from 3 to 7 parts aggregate to 1 part epoxy binder. The proportions suggested are applicable only to aggregates in the 2.60 to 2.80 specific gravity range. Aggregates having specific gravities above or below these values will probably require adjustment of the suggested proportions. The trial batch procedure will assist inexperienced field personnel in obtaining the proper proportions of aggregate and binder in preparing the larger field batches. Trial batches are not necessary in the use of epoxy grout for filling cracks, placing dowels, and as a bonding medium between plastic and hardened portland cement concrete. The two components of the grout usually will be mixed in the proportions specified by the producer without the addition of fillers or aggregate.

2.2.10.8 *Field Mixing and Batch Size.* Small mechanical mixers of the drum type have been used successfully for mixing epoxy concrete and mortars. However, these mixers are difficult to clean thoroughly, and delayed cleaning can result in buildup of residual material making replacement of the mixer drum necessary. Toluene, the solvent used, also presents problems of toxicity, fires, and-possible explosions (toluene has a low flashpoint) due to the confining nature of the mixer drum. Usually the batch size needed will be small, and handmixing using metal pans with other appropriate tools will be advantageous and less hazardous. The maximum batch sizer will be limited by the manual labor capability to thoroughly mix the epoxy binder and aggregate. Experience has demonstrated that this will range from 200 to 300 pounds total (epoxy binder and aggregate). Prior to starting operations, the immediate onsite availability of all batch-weighted materials and the suitability and adequacy of mixing and placing tools should be carefully checked. A relatively short delay before adding the aggregate to the mixed epoxy binder can mean loss of the binder due to the accelerated chemical reaction. Minor delays can be tolerated provided the mixed epoxy binder is spread in a thin layer, 1 inch or less, in the mixing pan. The container and mixing sequence of the epoxy and polysulfide curing-agent components should be as stated in paragraph 2.2.10.6. The mixed epoxy binder is then transferred to the mixing pan or the drum of the mechanical mixer. The total amount of aggregate incorporated in epoxy concrete may be greater if the aggregates are divided into coarse and fine fractions before being added to the binder. In mixing of epoxy concrete the fine aggregate fraction should be added to just below practicable workability (i.e., a slightly rich mix) and then the coarse fraction added to the carrying capacity of mortar while still retaining placeability and finishing properties.

2.2.10.9 *Protection of Repaired Areas From Weather and Traffic.* Repaired areas should be protected as follows:

a. Temperature. Pavement repairs made when ambient temperatures during the following 24 hours may be 60°F (15.6°C) or lower require limited protection to maintain the epoxy concrete or mortar at temperatures which will provide a reasonably normal hardening rate. The use of tarpaulins supported several inches above the surface of the repaired area will help to maintain the desired conditions provided the temperature difference or drop is not too great. Heated enclosures may also be used to provide effective temperature conditions.

b. Water. The formulation of the epoxy-resin grout and binder, described in the Federal specification, is such that moisture in or on the surface of the slab area being repaired does not affect bonding properties; however, free water should not be present. During the early hardening stages, which may vary from 2 to 12 hours depending on weather conditions, the epoxy mortars and concretes should be protected from the rain.

c. Traffic. The repaired areas should be barricaded to prohibit traffic of all types until the epoxy concrete or mortar has hardened. The time interval over which protection against traffic should be maintained will vary with weather conditions; but, when appropriate environment is provided or prevails, it will usually be less than 24 hours. [Note: Compressive and flexural strengths of 7,000 and 1,000 pounds per square inch (lb/in^2), respectively, have been obtained on 1.7 epoxy-aggregate mixes cured at 70°F (21°C) for 20 hours.]

2.2.10.10 *Cleaning of Equipment and Tools.* Due to the nature of the hardened epoxy systems, all tools and equipment must be thoroughly cleaned before the epoxy materials set. Toluene, xylene, or other aromatic petroleum solvents hazard. In the cleaning operations the workmen must wear solvent-resistant gloves; and, since even the vapors will break down natural skin oils, the use of protective creams is desirable.

2.2.10.11 *Safety and Health Precautions.*

a. General Precautions. The materials used in the two epoxy systems and the solvents used for cleanup do not ordinarily present a serious health hazard except to hypersensitive individuals. They may be handled with complete safety if adequate precautionary measures are observed. Handle only in well-ventilated areas. Prevent skin contact. Wear protective clothing and goggles when possible contact is anticipated. Wear goggles to protect eyes from the curing agent in the polysulfide component. This should be mandatory for persons doing the blending and mixing operations but is not so much a hazard for persons engaged in the placing operations. Maintain good housekeeping and personal hygiene standards. Remember the danger —solvents are a fire hazard.

b. Personal Sensitivity. The epoxy-resin component presents no hazard from vapor exposure, but a few individuals have developed a rash from skin contact. Therefore, adequate precautionary measures should be exercised. The polysulfide curing-agent component has an obnoxious odor from the polysulfide constituent, which may nauseate some individuals; consequently, inhalation of the vapors should be avoided or kept to an absolute minimum. The amine-type curing agents incorporated in the polysulfide constituent are caustic and may cause tissue damage on direct contact with the skin. Contamination of the eye by the polysulfide curing-agent component can cause severe damage very rapidly, and exposure to high vapor concentrations may also irritate the eyes and mucous membranes.

c. Personal Precautions. Although the constituents of the epoxy systems can create some health hazards, proper precautions will reduce these to minimum incidence confined principally to hypersensitive individuals. Wear rubber or other suitable impervious gloves whenever skin contact is possible. When gloves become contaminated, they should be discarded or reconditioned by washing in appropriate solvents, followed by soap and water. Contaminated gloves, clothing, working tools, etc., should not be removed from the work area except for discarding or cleaning. Wear protective clothing, such as coveralls, when engaged in the preparation and usage operations. Wearing of contaminated clothing should be prohibited. Apply protective creams on exposed skin areas when occasional contact occurs or is anticipated. Wear full face shields or goggles whenever droplet contamination is possible, such as during the blending and mixing operations. Restrict blending and mixing operations to open areas, or in buildings, to a well-ventilated hood system. Use disposable paper coverings in the work area where dripping or contamination is expected.

d. First Aid. Provide necessities for prompt treatment of accidental skin or eye contact. First-aid procedures in cases of accidental eye contamination consist of immediate and continued washing of the eye for at least 10 minutes with copious quantities of water; bathing the eye with normal saline solution; and referral to a physician if there is any question of serious eye involvement. Cleanse all skin areas thoroughly with soap and water following accidental or nonpreventative skin contact. If necessary, fresh alcohol, acetone, toluene, or methyl ethyl ketone may be used as a solvent; however, the use of such solvents should be kept to a minimum. In cases of spills, involved clothing should be immediately removed and decontaminated in the manner described herein for gloves.

e. Removing Source of Contact. If a workman develops a rash, the source of contact should be determined and eliminated. Treatment of the condition should be handled by a competent physician with full information furnished as to the probable cause.

f. Moving Hypersensitive Persons. Remove individuals who are sensitive to any of the epoxy system constituents from exposure until the condition is completely cleared. Limit subsequent contact with materials to a degree which proves to be tolerable. It may be necessary to remove highly sensitive workmen completely from the work area.

g. Obtaining Further Information on Health Factors. Some manufacturers of epoxy resins and some health agencies should be able to provide literature and other appropriate guidance on health and safety aspects. The Shell Chemical Corporation, Industrial Hygiene Bulletin SC 106-xx (latest edition) titled "Recommendations for Handling Resins and Auxiliary Chemicals" is an excellent treatise on many aspects of the health factors involved. This bulletin is readily available from any of their offices throughout the United States. Other manufacturers of epoxy resins should also be able to furnish somewhat similar information.

2.2.11 Floor Finish

For a detailed discussion of floor finish, see chapter 6, section III.

2.2.12 Curing

All concrete should be kept from drying out for at least 5 days (2 days for high early-strength portland cement). For slabs subject to severe wearing conditions and for special toppings, the minimum curing period should be increased to 7 days (3 days for high early-strength cement). Curing may be obtained by covering with waterproof paper sealed at all edges or any suitable method that will prevent the concrete from drying out. Proper curing will increase the strength and resistance to wear and will reduce the shrinkage and tendency to crack.

2.2.13 Liquid Hardeners

Liquid hardeners applied over friable, dusting concrete floors protect the surface against abrasion and shock caused by heavy traffic. Use low-viscosity solutions which penetrate deeply into the concrete.

2.2.13.1 *Preparation of Concrete Floor Surfaces.* Clean all dust, dirt, foreign particles, and oil or grease spots from concrete floors to which a liquid hardener is to be applied.

2.2.13.2 *Materials.* Use one of the following materials or an approved equivalent:

a. Sodium silicate (water glass): Commercial, 40° to 42° Baume (Be).

b. Magnesium fluosilicate& Crystalline salts plus zinc fluosilicate.

2.2.13.3 *Mixing and Applying Sodium Silicate.* Dilute sodium silicate just before using by adding 4 gallons of water to 1 gallon of sodium silicate. One gallon of this solution covers about 800 square feet of floor surface with one coat. Apply the solution as follows:

a. First coat Apply first coat with a mop or broom, brushing solution continuously over floor surface to get even penetration. Allow at least 24 hours for first coat to dry and harden. Scrub dried surface with hot water to remove the glaze which generally appears, then allow 24 to 48 hours for surface to dry completely. If floor is porous enough to absorb first coat without leaving a glaze, hot-water scrubbing can be omitted.

b. Second coat. Apply a second coat in the same manner as the first. Allow it to dry, scrub with hot water, and again dry for 24 to 48 hours.

c. Third coat. Apply third coat in the same manner. Allow it to dry thoroughly before using floor. Hot-water scrubbing is not needed on this coat.

2.2.13.4 *Mixing and Applying Magnesium Fluosilicate.* To 1 gallon of clean freshwater add a 2-pound mixture of crystalline salts of magnesium fluosilicate and zinc fluosilicate, at least ½ pound being zinc fluosilicate. Fluosilicates can be obtained as prepared solutions or as dry crystals. Dry crystals are more economical and can be mixed at the job with freshwater in wooden vessels. One gallon of this solution covers about 100 square feet of floor surface with one coat. Apply as follows:

a. First coat. Dilute the solution by adding 1 gallon of clean freshwater to each gallon of solution, or prepare a new solution of 1 pound of dry crystals to 1 gallon of water. Apply solution with a mop or broom, and brush it continuously over floor surface for several minutes to get even penetration. Allow at least 24 hours for drying before applying second coat.

b. Second coat Apply second coat, using undiluted solution of 2 pounds of crystals to 1 gallon of water. Follow same procedures as for the first coat. Allow at least 24 hours for drying.

c. Third coat. If floor is unusually friable or porous, apply a third coat, using same solution and application as for second coat.

2.2.13.5 *Costs.* Sodium silicate materials are cheaper than fluosilicates, but labor cost is greater because of the hot-water scrubbing of each undercoat.

2.2.13.6 *Comparative Effectiveness.* Laboratory experiments and actual use have generally shown little difference in effectiveness between sodium silicate and fluosilicate if both are applied properly. On smooth-troweled floors or dense surfaces, fluosilicate solution is less viscous and penetrates more easily.

a. Penetration of most hardeners, especially sodium silicate, is improved by applying the solution heated to about 170°F (76° F). Both sodium silicate and fluosilicate solutions become about half as viscous at 170°F as at 70° F (21° C). This change in viscosity is greater than that obtained by diluting the solution, which is sometimes recommended for the first coat.

b. Maximum penetration of hardener may not always be desirable. With rough, porous surfaces it is sometimes desirable to retain enough hardener at the surface for adequate reinforcement; use of more concentrated hardeners applied cold will probably give better results. On rough or porous surfaces, 42° Baume sodium silicate solution diluted 1 to 3 or 1 to 2.5 is preferable to fluosilicate solution.

c. Most liquid hardeners sold under trade names have a base of sodium silicate and magnesium fluosilicate, with a small amount of zinc sulfate, or other materials added.

d. Sodium silicate and magnesium fluosilicate with or without added materials are favored because of their availability, ease of mixing and application, ability to harden surfaces satisfactorily, and comparatively low cost.

2.2.13.7 *Varnish Seal Treatment.* A varnish seal is effective to prevent dusting of concrete floors that are subjected to heavy foot traffic. It provides a seal for subsequent waxing of floors in entrances, lobbies, and other areas where appearance is a prime factor. Use a sealer conforming to Federal Specification TT-S-176. Apply the sealer liberally by brushing it into the pores of the concrete. After the sealer has been allowed to dry, buff it with a floor-polishing machine. If certain areas appear lifeless, repeat the process until the pores of the concrete are filled.

SECTION III—MOISTURE CONTROL

2.3.1 Moisture Damage

The backfill around foundations is usually less dense than the surrounding natural, undisturbed earth. Thus, the foundation area has a tendency to be a reservoir of excess surface and underground seepage water, unless it is properly drained. Confined water builds up hydrostatic pressure against foundation surfaces where cracks, porosity, or voids in joints of foundations walls will permit water to seep into the structure and cause wet walls and floors. It drainage is neglected for a long time, overirrigation of the bearing soil may reduce its stability and lead to major dislocation of the foundation. Where the nature of subgrade soil resists, deters, or stops free drainage of subgrade water, waterproofing of usable areas below grade (such as basements, cellars, pools, pits, vaults, igloos, tunnels, utility trenches, and manholes) is usually necessary. The prolonged neglect of such a condition may cause shifting or rotation of the footings or reduction in the load bearing capacity of the soil under the foundation resulting in serious damage to the structure.

2.3.2 Causes and Control of Ground Water

Although there are several causes and controls for specific ground water conditions, improved drainage is the basic solution to the most common ground water problems. See figure 2-12.

2.3.2.1 *High Water Table.* Moisture in structures caused by a high water table can be drained away from the foundation by installing a drainage system. This is usually the most effective and economical method of maintaining dry foundation walls and slabs on grade. Two drainage systems in general use are described below.

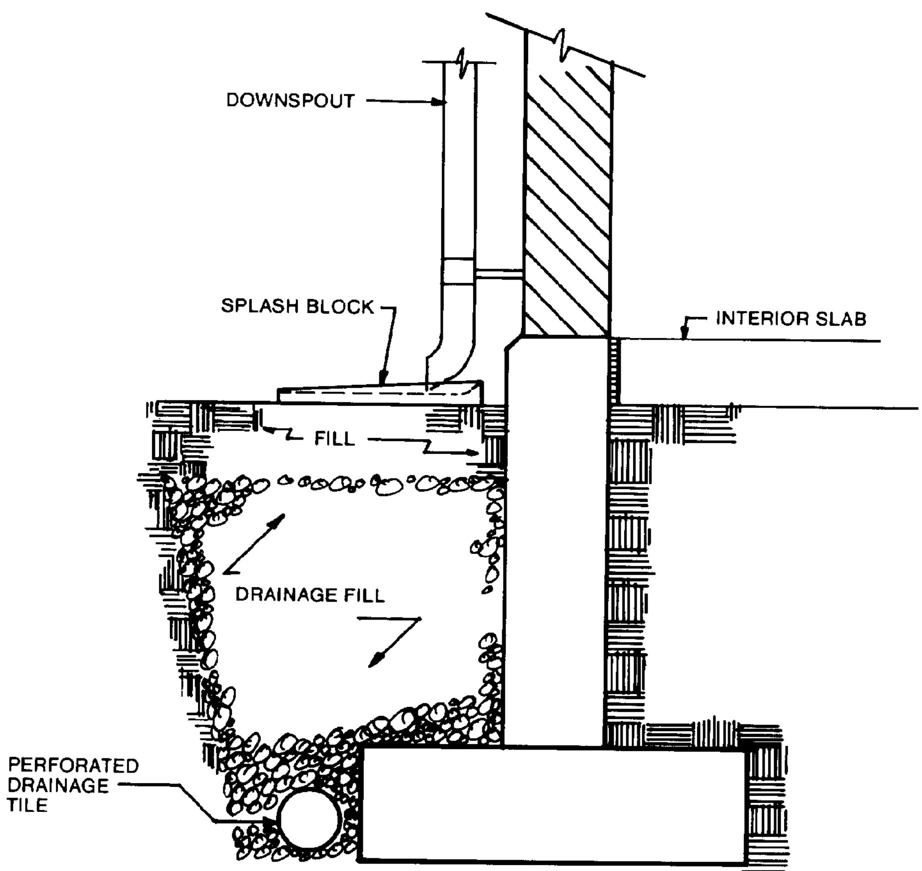


Figure 2-12. FOUNDATION DRAINAGE.

a. Drainage Pipe. The earth around the foundation walls is excavated to the bottom of the footing with enough width for working space. See figure 2-13, a foundation wall is to be exposed, care should be exerted to assure that the stability of the wall and the earthbank is maintained. Special care should be taken in loose sand, saturated clay, or a wall having an outward (horizontal) thrust imposed upon it. Perforated or plain tile pipe or perforated plastic pipe such as polyvinylchloride (PVC) is installed next to the bottom of the footing, pitched with minimum slop of ½ inch in 10 feet in the direction of the intended runoff. Perforated pipe should be laid with closed joints. Plain tile pipe should be laid with open joints having the upper half covered with a bituminous-treated fibrous building paper or suitable plastic film to prevent sand or soil from clogging the drainpipe. To be effective, a drain should generally be pitched from a high point around the perimeter of the building to a low point below the floor slab where the connection or sump is located. Footing drains connect independently of all other drains into storm sewers, dry wells, or outfalls available for free drainage of water. Drains may also flow into a sump with a float-controlled electric pump. Footing drains that connect to storm sewers or other outfalls should be designed with sufficient drop to assure that the storm sewer does not flood back to the foundation wall. Never connect a storm drain to a sanitary sewer. The drains shall be covered with a bed of at least 1 foot of graded, crushed stone or gravel. Drainpipe sizes and stone drainbed areas (cross section) shall be determined by the estimated volume of water to be drained, the length of run, and the slope of the drain.

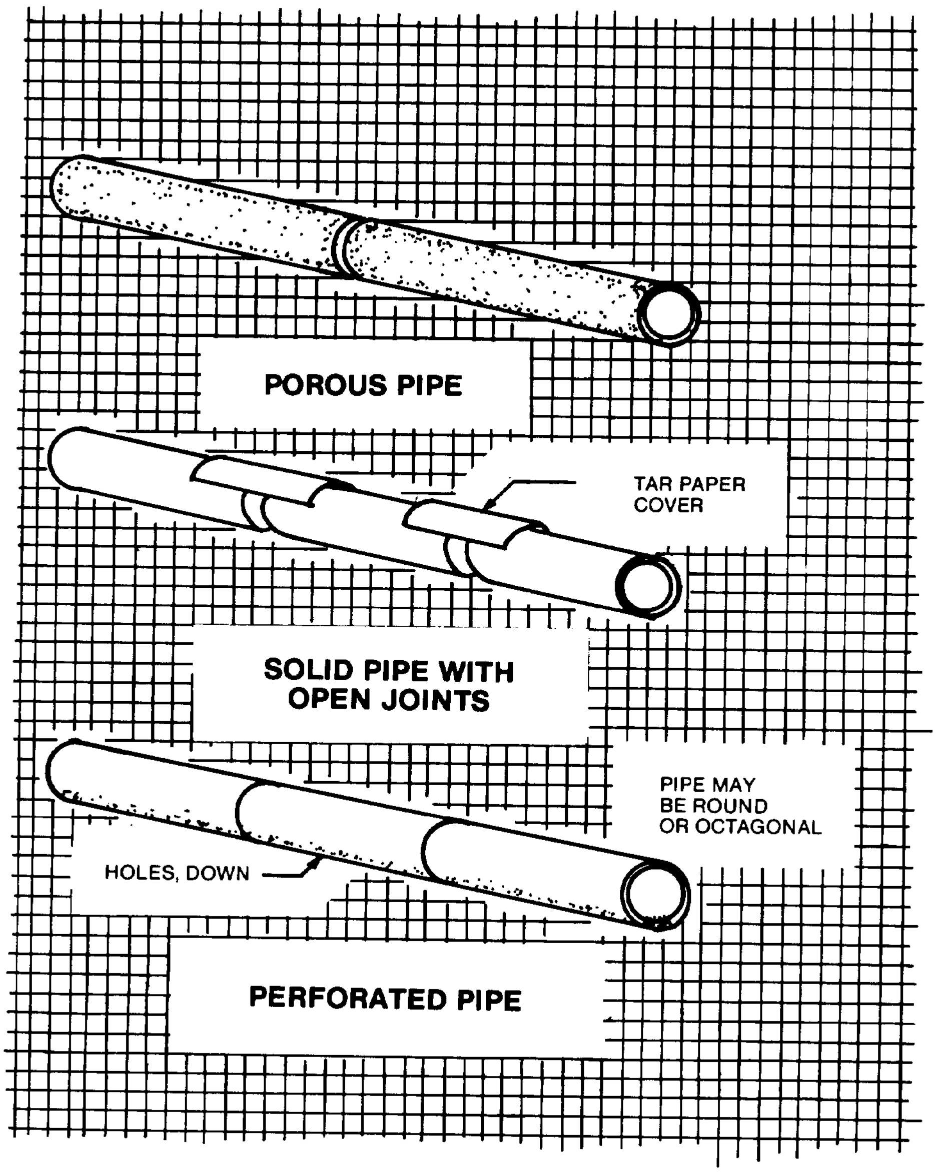


Figure 2-13. DRAINAGE PIPE.

b. Gravel Drain. A stone drain bed laid at the bottom of the footings, approximately 2 feet wide and not less than 1½ feet deep, shall be installed similar to the draintile described above.

2.3.2.2 *Roof Drainage.* Where roof drainage causes a foundation water problem, gutters and downspouts should be installed, preferably connected to a storm sewer. Gutters that are improperly hung or allowed to become clogged will overflow and lose their effectiveness. Leaks in gutters should be repaired promptly. Splash blocks or draintile should be installed in the absence of storm sewer connections to prevent pooling of water below downspouts.

2.3.2.3 *Surface Drainage Toward Building* The drainage of surface water toward a building can be reversed by sloping the ground surface away from the foundation wall. Where that is not practical, ditching or installing drains will serve the same purpose. The general grade of crawl spaces should not be lower than the surrounding area, which should be graded to drain way from the building.

2.3.2.4 *Infiltrating Water.* Ground water under hydrostatic head will seep through minor cracks, construction joints, porous concrete, and porous masonry. Direct leaks caused by holes, settlement cracks, complete fracture through walls and slabs, around utility pipes, conduits, ducts and other utility services penetrating foundation walls and slabs are due to improper installation of sleeves, caulking, or inserts. These leaks must be investigated and repaired in conjunction with other water control measures.

2.3.2.5 *Utility Leaks.* Breaks in water, sewage, heating, and drain pipes should be repaired as soon as discovered. Such conditions will become evident by the improper functioning of the utility involved. However, a thoroughly waterproof foundation of slab may not show any evidence of moisture or the location of such a leak. If a serious break of this nature is not discovered and repaired, it may affect the stability and load bearing capacity of the soil. This will result in serious damage to the structure. When a break is suspected, locating the break may require opening cuts in the slab or excavation of the soil at exploratory points. After locating and repairing the damaged utility, the foundation is to be restored to designed conditions.

2.3.3 Condensation

Condensation is caused by humid air coming in contact with cold surfaces. If it is a seasonal condition, the cost of correction might not be justified for the nature of the usage of the space. If the condition is constant and of such extent as to be harmful to the structure or render the space unusable for its designated purpose, the condition should be eliminated.

2.3.3.1 *Condensation in Interior Spaces.* Condensation in interior spaces may be eliminated or alleviated by one or more of the following methods:

a. Dehumidification of room air by mechanical means.

b. Insulation of walls including a vapor barrier on the warm side of the insulation.

c. Ventilation of the room to prevent the air from cooling to the dewpoint.

d. Where thoroughly dry conditions are required, a special system shall be designed by a qualified engineer.

2.3.3.2 *Condensation in Crawl Spaces.* In crawl spaces or “dead” areas under structures with no basements, moisture-control problems other than building drainage develop from condensation of moisture rising from damp soil. The ideal method of preventing ground moisture from entering the building is to provide an impermeable vapor barrier on insulation in floors and walls. In existing buildings, this is not practical unless it is done during major renovation. The most practical solution is to provide a soil cover of water-resistant material. In the past, 55 pound roll roofing has been the most widely used and successful soil cover. However, 6 mil (0.006 to 0.5 inch) polyethylene plastic sheeting is more effective and easier to handle. The effective life of these plastic covers when exposed to air or under slabs has not been established. Soil covers may be rolled out on the soil from foundation wall to foundation wall. It is not necessary to form a complete seal over the soil; however, at least 90 percent of the soil should be covered; cracks should be limited to 1 inch. Removal of trash and debris and leveling of sharp dips and mounds in the soil will increase the life of the cover.

2.3.4 Moisture Control in Subsurface Structures

Moisture in subsurface structures results from condensation or seepage-or both. Correction may range from simple solutions including dehumidifying or using waterproof paint to drastic measures such as excavation and waterproofing or diverting water sources. Three measures are used to control moisture: plugging leaks, eliminating causative water problems outside the structure, and controlling dampness inside the structure. Correction of condensation-related problems is detailed in paragraph 2.3.3.1.

2.3.4.1 *Moisture Seepage.* Seepage includes the passage of moisture or water through masonry walls or floors from adjacent surfaces. In mild cases, it may resemble condensation and can be tested using a 12-inch square of smooth aluminum foil taped to the masonry wall. If, after several days, moisture appears on the wall side of the foil, seepage is present.

2.3.4.2 *Waterproof Painting.* Unless cracks appear at the source of seepage, moisture control may be established by painting the surface of the walls with a waterproof paint. Ready-mixed paints must be applied to a dry wall which has been prepared by removing dirt and efflorescence with a wire brush, chipping off all loose mortar, and patching holes. The same procedures are followed for dry powder paints, however, the wall must be wetted before painting. Painting is done using a stiff brush. The paint must be carefully worked into all pores of the surface to seal the wall. Two coats are required and the wall should be inspected to insure that all pores are sealed.

2.3.4.3 *Water Leakage.* Leakage occurs from openings in the walls or floors. These may include defective joints, mortar cracks, settlements cracks, or holes resulting from damage or around pipes passing through the wall. In all cases, steps should be taken to seal the opening and eliminate conditions causing the problem.

2.3.4.4 *Repairing Cracks.* Leakage problems associated with cracks may be solved by plugging the crack using patching cement or silicone caulk as discussed in chapter 4, paragraph 4.3.6. Cement should be used only in cases which show little likelihood of continuing shift in the structure. Hydraulic cement must be used in those cracks where running water is present.

2.3.4.5 *Exterior Moisture Control.* In all cases of leakage, steps must be taken to control the source of moisture. This may include control of surface and subsurface water as described in paragraph 2.3.2, or foundation waterproofing as described in paragraph 2.3.4, or both.

2.3.5 Foundation Waterproofing

If interior surface maintenance is insufficient to control moisture, excavation and exterior surface waterproofing may be required.

2.3.5.1 *Preparation of Wall Surfaces.* Excavate a trench wide enough for working space around the outside of foundation walls and to the bottom of the footings. Thoroughly clean the exposed surfaces with water, detergents, live steam, or other available agents. Procedures for steam cleaning are detailed in chapter 4, paragraph 4.3.9.4. Carefully examine the exposed surfaces for cracks, holes, fractures, and other damage that would permit moisture to penetrate the walls. Repairing concrete and masonry walls are outlined in chapter 4.

2.3.5.2 *Bituminous Mopped-On Membrane.* Bituminous mopped-on multiple membrane is one of the most positive methods of waterproofing foundation walls subject to considerable hydrostatic pressure. Membranes are of bituminous-saturated felts or fabrics. Roofing-grade, hot coat-tar pitch (conforming to ASTM D-450) or asphalt (conforming to ASTM D-312) is used to mop on the membranes. Five plies of membrane are recommended for hydrostatic pressures of 12 feet. All component materials used in any one application should be the products of one manufacturer, and his application instructions should be followed carefully. Membranes should be applied free from wrinkles and buckles, with each ply coated completely to separate one from another. After the last ply has been placed, the entire surface should be mopped with coat tar or asphalt, according to membrane type (i.e., 70 lbs of coat tar per 100 ft^2 and 60 lbs of asphalt per 100 ft^2 of surface). The final coat should be protected from backfill by a layer of fiberboard embedded in the hot coat. Care should be taken not to rip, scar, tear, or cut the finished membrane during backfilling.

2.3.5.3 *Nonbituminous Sheets.* Membranes of pure plastics, thermoplastics, metal (usually copper or aluminum), and sheathed fibrous build mg papers are usually applied in more than one layer. They are embedded in portland cement mortar, mastics, plastic cements, or bituminous coatings. All component materials should be products of one manufacturer and used in strict accordance with his instructions.

2.3.5.4 *Cold Asphalt Application.* A primer coat of thin cutback asphalt (conforming to ASTM D-41) should be applied to porous masonry. A heavy coat of asphalt mastic (conforming to Federal Specifications SS-A-694) should be troweled on the primer coat at least **c** inch thick at the rate of 1 gallon per 12 square feet. Where trowel application is not feasible, two coats of asphalt mastic should be brushed over the primer coat at the rate of 1 gallon per 50 square feet per coat. On concrete, a nonfibrous asphalt emulsion primer diluted with 15-percent cool water should be applied by brush or spray. At least two heavy coats of nonfibrous asphalt emulsion should be brushed or sprayed over the primer coat at the minimum rate of 1½ gallons per 100 square feet per coat.

2.3.5.5 *Hot Asphalt Application.* A coat of penetrating asphalt primer (conforming to ASTM D-41) should be mopped or sprayed over the surface to be treated. Coverage should be 200 to 400 square feet per gallon, depending on the porosity of the surface. Two coats of hot asphalt (conforming to ASTM D-449) should be mopped or sprayed evenly over the entire surface at the rate of 25 pounds per 100 square feet per coat. The finished coat should be bright, glossy black; and dull areas should be recoated.

2.3.5.6 *Cold Coat-Tar Pitch Application.* A penetrating creosote oil-base bitumen (conforming to ASTM D-43) should be brushed or sprayed evenly over the surface at the approximate rate of 2 gallons per 100 square feet. Application should be repeated until all pores and voids are filled but should not exceed four coats. Each additional coat should be applied at right angles to previous coats to provide full coverage. After the last primer coat has been absorbed and the surface is dry, a complete brush coat of coat-tar bitumen (80° to 100° F or 26.7° to 37.8° C) should be applied at the approximate rate of ½ gallon per 100 square feet. Areas that are not glossy black should be recoated. The finished coat should be hard and dry before back-filling is begun.

2.3.5.7 *Hot Coal-Tar Pitch Application.* A coat of creosote oil primer (conforming to ASTM D-43) should be brushed evenly over the surface at the approximate rate of 1 gallon per 100 square feet. Two coats of hot coat-tar pitch (conforming to ASTM D-450, Type A) should be mopped over the primer coat at the approximate rate of 25 pounds per 100 square feet per coat. Pitch should be heated until it is completely liquid but not heated more than 375° F (190.6° C). Backfill should be placed and tamped immediately after the last coat has been applied.

2.3.5.8 *Metallic Type Waterproofing.* Metallic powder may be either mixed with water and applied as a brush or sheath coat, or mixed with cement, sand, and water, and applied as a mortar or plaster coat. The metallic powder oxidizes and expands to fill the voids left by evaporating water. This treatment resists considerable water pressure. Manufacturer's instructions must be carefully followed in preparing and applying the material. Use of metallic waterproofing will be limited to interior applications below grade where temperature differences and surface movement are at a minimum. Where exterior walls are inaccessible and waterproofing must be applied to the interior face, the metallic method is recommended. Metallic-type waterproofing shall consist of finely ground, clean iron of carefully graduated sizes, meeting the standard screen analysis. See table 2-1.

Table 2-1. Mesh sizes for Standard Screen Analysis

Standard screen mesh size	Percentage retained
35	None
40	10
60	35
100	50 to 70
200	80 to 90

The iron shall be mixed with a chemical oxidizing agent that shall be not less than 5 percent or more than 10 percent by volume of the total mixture. The iron-oxide content shall not exceed 5 percent by volume. Material shall not contain dirt, paraffin, or bitumen of more than 0.1 percent by volume. Only enough mortar with metallic material for immediate use should be mixed because it should not be retempered. The wall should first be exposed, cleaned, and roughened to provide a key for the waterproofing materials. Holes, cracks, and other soft or porous places should be cut back to solid material, cleaned, and pointed with mortar. All pipes, bolts, and similar construction should be caulked with lead wool and waterproof cement and made watertight. Surfaces should then be dampened with clean water and given one bonding coat composed of 1 part cement and 1 part metallic material mixed to a creamy consistency and applied with bristled brushes. The surface should be thoroughly brushed to seal all pores rather than merely provide a surface veneer. This is followed by application of two coats of mortar composed of 1 part portland cement, 3 parts sand, and 25 pounds of metallic material to each bag of cement. This first coat should be troweled on and scratched when partially dry. The second coat, mixed to a heavy brushing consistency, should be brushed on carefully and floated with wood floats. Total thickness of all coats should be approximately $^{5}/_{16}$ to **d** inch. After each coat has set but not dried out, surfaces should be wetted down frequently over a period of at least 72 hours. Sufficient time should be allowed between coats to permit thorough oxidation of the material. If rust color is undesirable, cover wall with one or two coats of a waterproof cement-water paint. Do not apply until waterproof coating has completely oxidized and dried out.

2.3.5.9 *Cement Plaster Waterproofing* A method of waterproofing below-grade walls is to plaster exterior surfaces with cement mortar. This mortar may be made plain, or water resistance can be increased by adding calcium stearate, ammonium stearate, or other equivalent water repellent in amounts equal to 3 percent of the weight of the cement. Although the cement plaster method is efficient, its major defect is rigidity. Structural defects which crack the wall may also crack the cement plaster. The method may prove adequate for a wall which is subject only to occasional dampness and not continuous water pressure.

2.3.6 Waterproofing Underground Structures

2.3.6.1 *General.* Due to the advent of numerous underground structures (fallout shelters, command posts, missile silos, communication centers, ammunition storage areas) into the military real property inventory, the problem of waterproofing underground structures has become important. A detailed discussion of the waterproofing is presented using the ammunition igloo as the model for the discussion. The ammunition igloo is the underground structure most frequently encountered. However, the principles discussed are valid for any underground structure. Prior to initial repairs, the structure should be carefully examined to definitely establish that the undesirable conditions are caused by leakage and not by condensation or other causes. Modification of storage arrangements or physical plant layout, improved ventilation, dehumidification, or other means to prevent condensation may correct the problem.

2.3.6.2 *Preparation for Waterproofing.* Remove the earth cover from the entire structure to the ledge of the foundation footings, including the rear end wall, and stockpile for replacement. When removing the earth, be careful not to damage the concrete structure or the draintile near the footings. Scrape the concrete structure to remove all dirt, foreign matter, and any loose adherent material. Remove as much as is practicable of the old waterproofing layer if the new waterproofing is not compatible. If the new waterproofing is compatible, only the damaged or loosely adherent portions of the old waterproofing need be removed. Inspect the cleaned surfaces. Remove all sharp edges, ridges, abrupt cleavages, bolts, and severe roughness. Fill all cracks and openings with port-land cement grout. Thoroughly bond the grout to the old concrete, trowel smooth, and allow to cure. Clean all cracks, fill with asphaltic plastic cement (conforming to Federal Specification SS-C-153) and cover with two layers of 30 pound roofing strips (conforming to ASTM D-226) not less than 6 inches wide, embedded in two layers of asphalt plastic cement c inch in thickness, centered over each crack. Cracks ¼ inch or more in width shall, in addition to the above, be covered with sheet-metal strips 7 inches wide, sandwiched between the two roofing strips 8 inches wide, and heavily embedded in asphalt plastic cement. Cracks ½ inch and larger should be filled with a mix composed of 8 parts asphalt emulsion and 2 parts portland cement (8:2 mix) prior to installing felt strips. Seal the horizontal joint between the foundation and barrel with this 8:2 mix (trowel into the joint and spread 18 inches wide). Firmly embed a 12-inch-wide strip of woven glass fabric conforming to ASTM D-1668 centered over the joint, and coat with a second application of the above mixture. Rough, pitted, honeycombed areas may also be filled with the 8:2 asphalt emulsion, portland cement mixture in lieu of cement grout where conditions warrant. When the concrete is found to be porous and saturated with water, dry out adequately to provide a completely dry surface before the prime coat is applied. Normally, the drying-out period is about 14 days.

2.3.6.3 *Application of Waterproofing Membrane.* Area to be waterproofed will comprise the entire structure, including the barrel, the rear end wall, the front wall cant, the foundations to the footings, and at least 3 inches of the footing ledge. Inspect and repair as required to provide a reasonably smooth surface. Coat the entire surface to be waterproofed with primer (complying with current Federal Specification SS-A-701), applied at not dry for at least 2 days. Apply asphalt emulsion (complying with current ASTM D-1187, Type A over the prime coat at a rate of not less than 3[1/2] gallons per 100 square feet. See figure 2-14. Apply two plies of glass cloth fabric, which will cover the entire area to be waterproofed, over the fresh coating of asphalt emulsion. The fabric should be draped vertically over the barrel. Endlaps, when required, should be not less than 12 inches and should be cemented over the lower ply. Sidelaps in each ply should not be less than 2 inches. Lay fabric vertically on the end wall and lap at least 12 inches on the barrel for anchorage, without wrinkles and buckles; firmly pull into the emulsion, smooth by hand to work out wrinkles, and make tight to the lower walls for adhesion to prevent floating as the emulsion is applied. See figure 2-15. Saturate the fabric completely by spraying asphalt emulsion at a rate of not less than 4 gallons per 100 square feet at approximately 80 lb/in^2 pressure. Allow to dry for at least 2 days. Apply the finish coat of asphalt emulsion over the entire area to be waterproofed using not less than 2 gallons per 100 square feet, giving special attention to thin areas and areas in which the fabric is insufficiently coated. See figure 2-16. Inspect the coating after it has dried completely and touch up any bare spots or defects. Dust the waterproofed area with talc or dry portland cement, using not less than 11/2 bags per igloo. Lay the slip-sheet cover (complying with current Federal Specification SSR-501, Class A, 65 lb, Mica Surface) vertically with a lap of not less than 2 inches at the side. Sandbag the sheets to hold in place at the crown lap until the earth cover is replaced. See figure 2-17. Inspect the draintile and verify that tile size is adequate; that the highest point is 1 to 2 feet minimum below floor level; that the tile is properly laid to drain; that it is not obstructed with sediment or other objects, as disclosed by lamping or rodding; that the discharge is to an area with definite slope away from igloos; and that the discharge end of tiles are screened to prevent entrance of rodents. Replace the earth cover carefully in two stages using procedures that will protect the waterproofing from damage. Remove rocks from the earth to the extent that it shall contain not more than 15-percent stone or gravel, all passing a 1-inch sieve. In the first stage, replace the earth halfway up the height of the igloo and allow to settle for about 14 days, or until noticeable compaction has occurred. See figure 2-18. At this stage, examine the slip sheets for possible breaks at the earth line and correct them by splicing and patching. In the second stage, replace the earth to the top of the barrel retaining wall and maintain at the same height the length of the igloo. Maintain a slope of approximately 1.75 on 1, free of vertical and horizontal depressions.

Maintain sufficient compaction to avoid appreciable slump, slippage, or shrinkage of the finish grade. Bulldozers and other heavy equipment must not approach closer than about 3 feet of the igloo. Finish to grade, hand-rake, and smooth the earth to provide natural drainage. The earth should be provided with vegetation of a type consistent with the landscaping plan for the installation. Remove dirt and other foreign materials from the concrete apron of each igloo, and assure that the drainage outlets are exposed and opened.

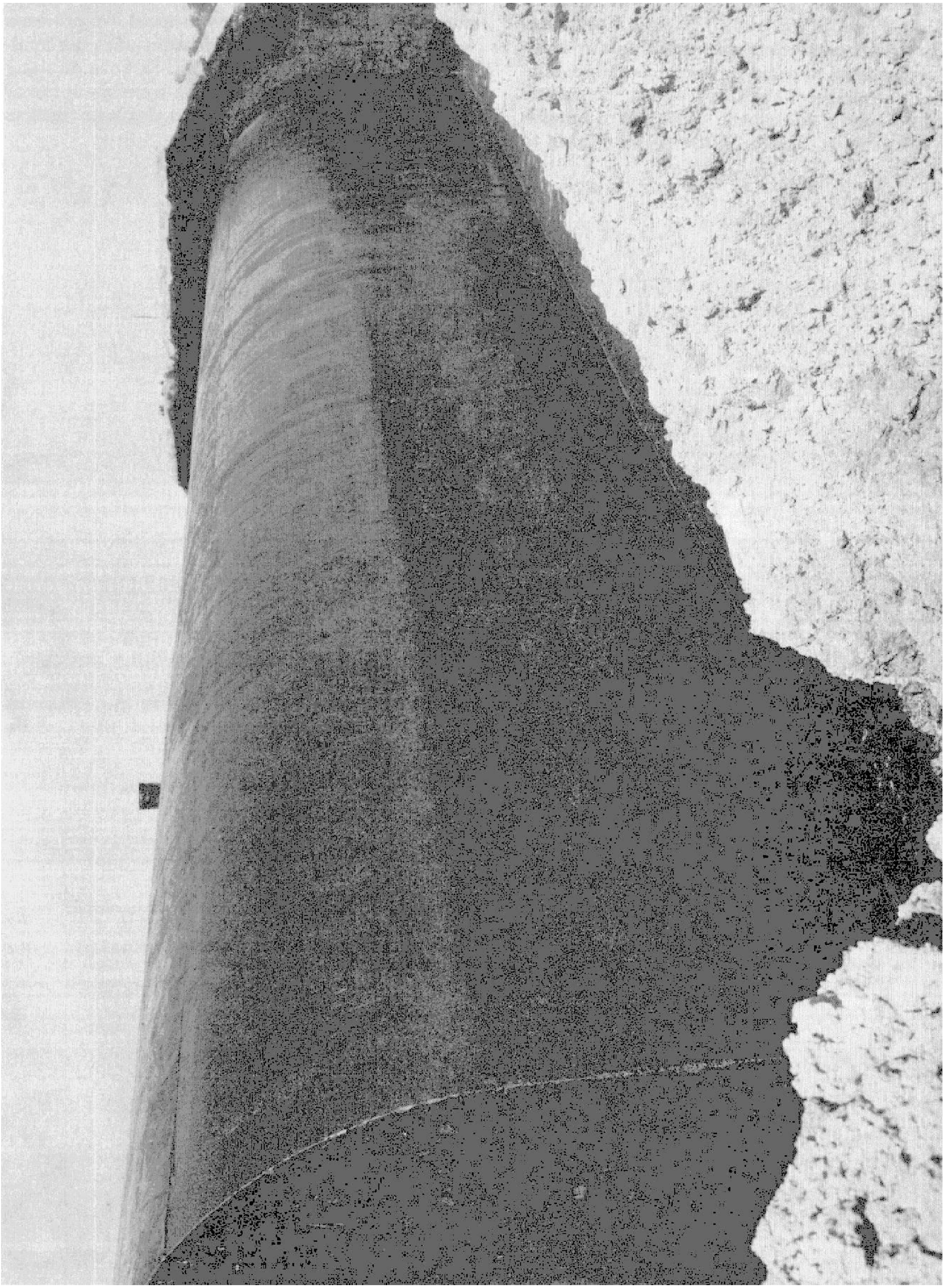


Figure 2-14. WATERPROOFING IGLOO—PRIME COAT.

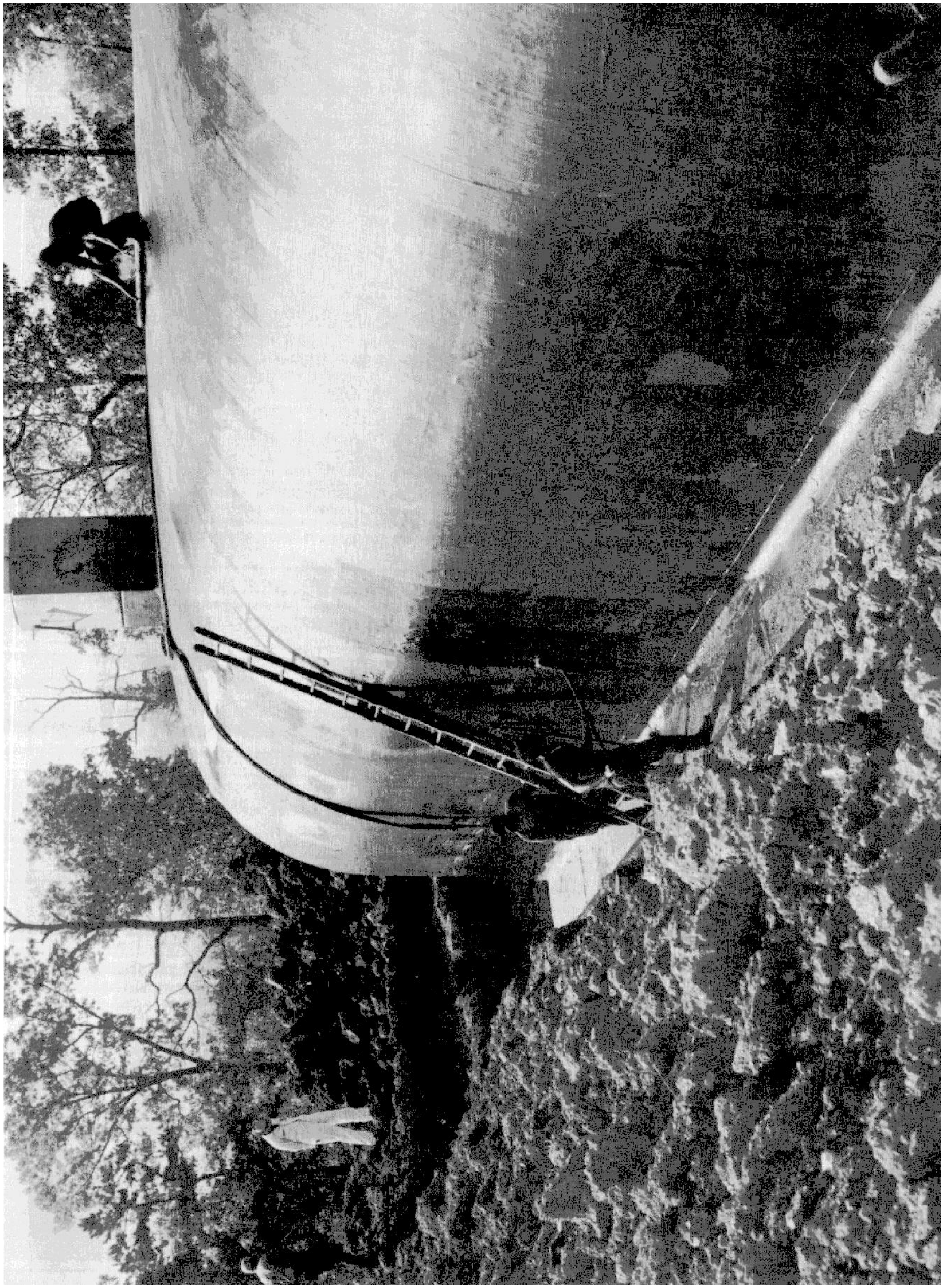


Figure 2-15. WATERPROOFING IGLOO—GLASS FABRIC.

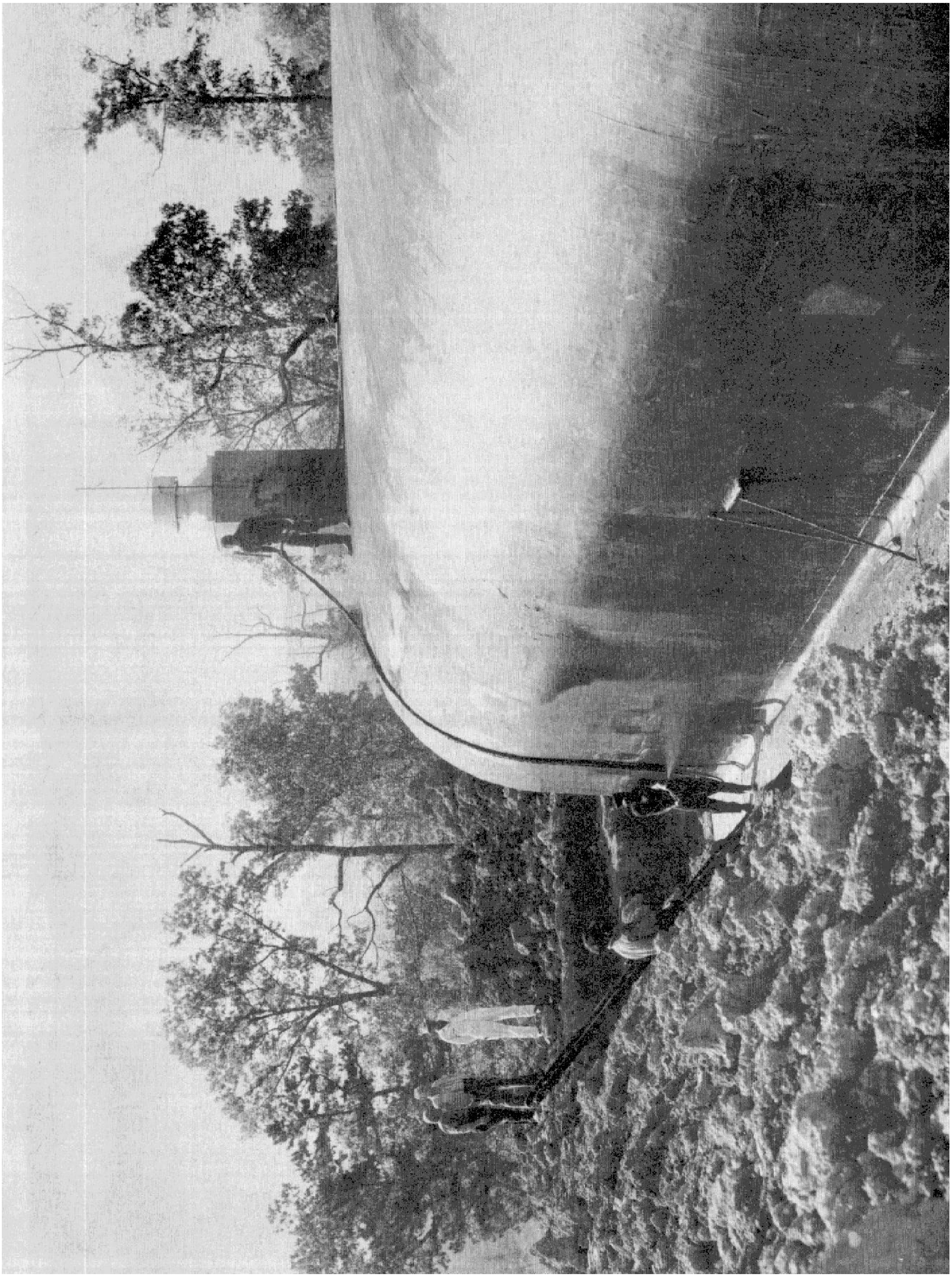


Figure 2-16. WATERPROOFING IGLOO—FINISH COAT.

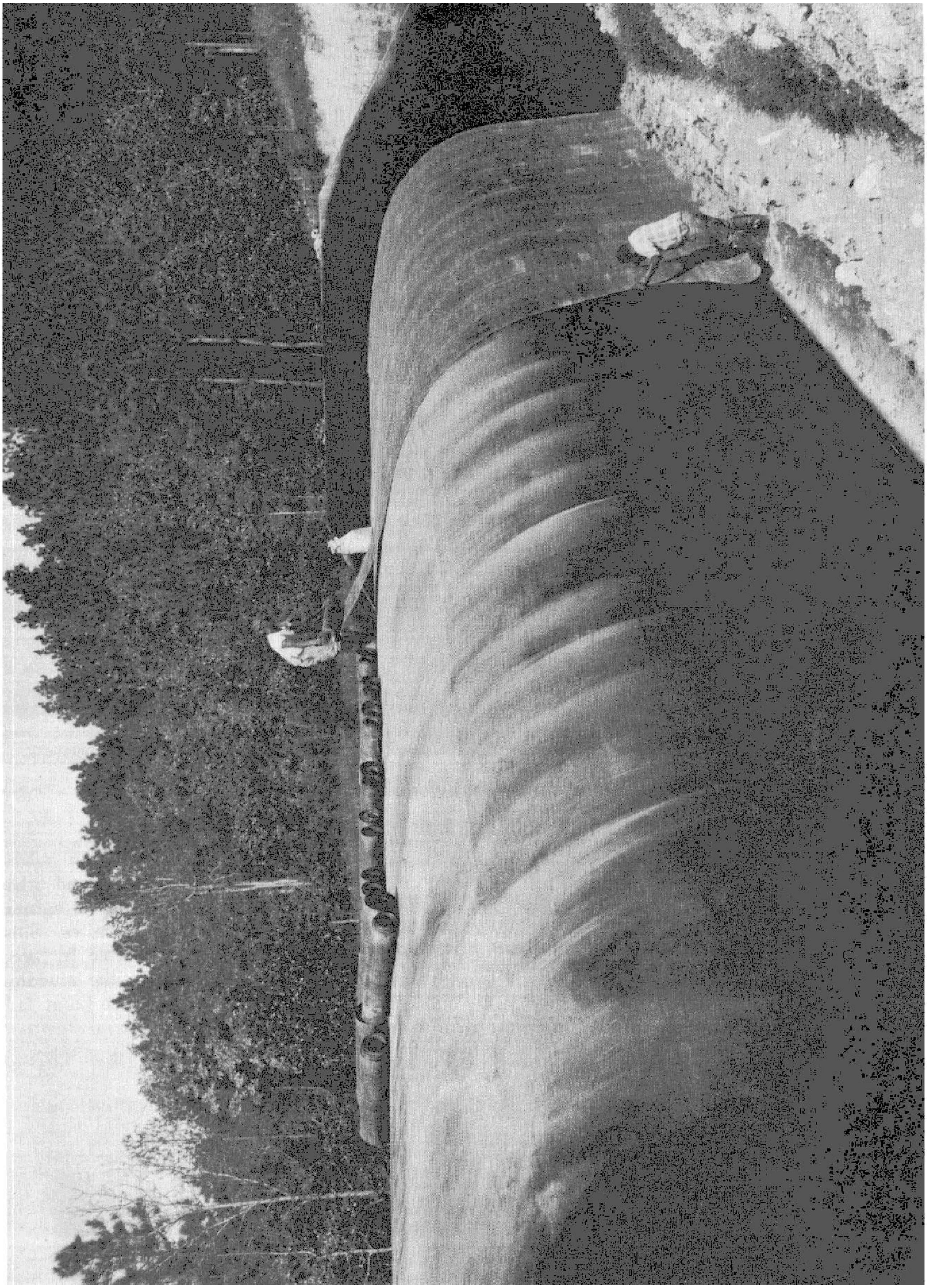


Figure 2-17. WATERPROOFING IGLOO—SLIP SHEET.

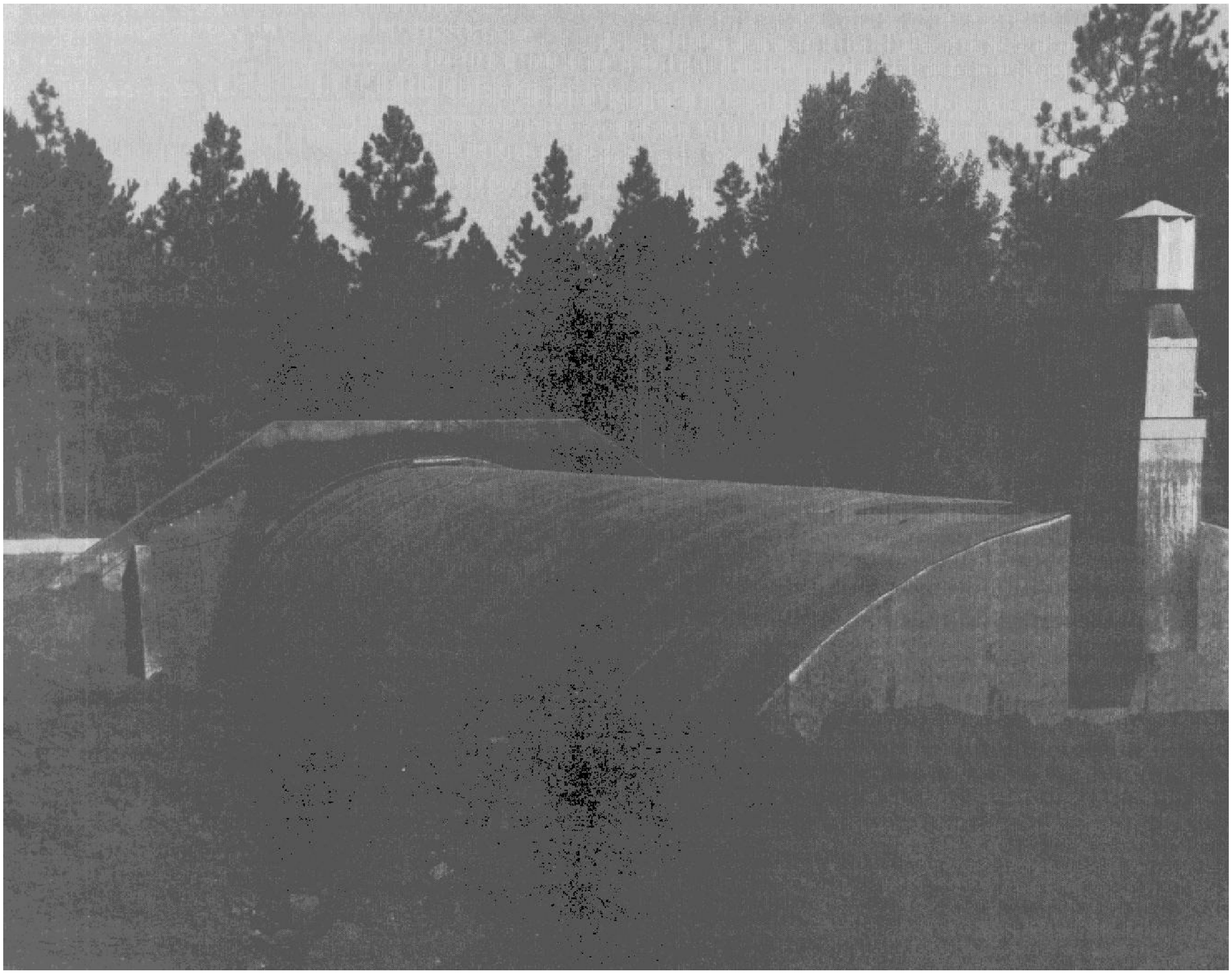


Figure 2-18. WATERPROOFING IGLOO—BACKFILL

SECTION IV—CRAWL SPACES

2.4.1 General

Considerable deterioration extending from foundation to building superstructure can be caused by neglect of crawl spaces, especially in climates where it is necessary to enclose the space to maintain comfortable floor temperatures. Unventilated crawl spaces contribute materially to rapid absorption of moisture into structural wood and other materials, and the spaces soon become a natural habitat for fungus growth and termites. Sills, joints, and subflooring may be affected by wood decay. Condensation may occur in the studding spaces above the floor level and cause paint failures.

2.4.2 Housekeeping

Routine good housekeeping requires that crawl spaces be kept clean, clear, and accessible. An accumulation of rubbish in the space may provide a natural harbor for insects and rodents, as well as impede access and possibly interfere with drainage. Scrap wood is a clear invitation to termites. Crawl spaces should be checked periodically, and an adequate program of pest control carried out. Disorganized storing of any materials in crawl spaces should be prohibited. Crawl spaces should be graded to prevent wet areas. Such areas breed mosquitoes, cause fungus growth, and weaken soil-bearing under footings. All ventilation openings should be covered with suitable hardware, cloth, or copper screening to prevent entry of birds and rodents. See figure 2-19. Access doors to crawl spaces should be provided with a suitable padlock and kept closed.

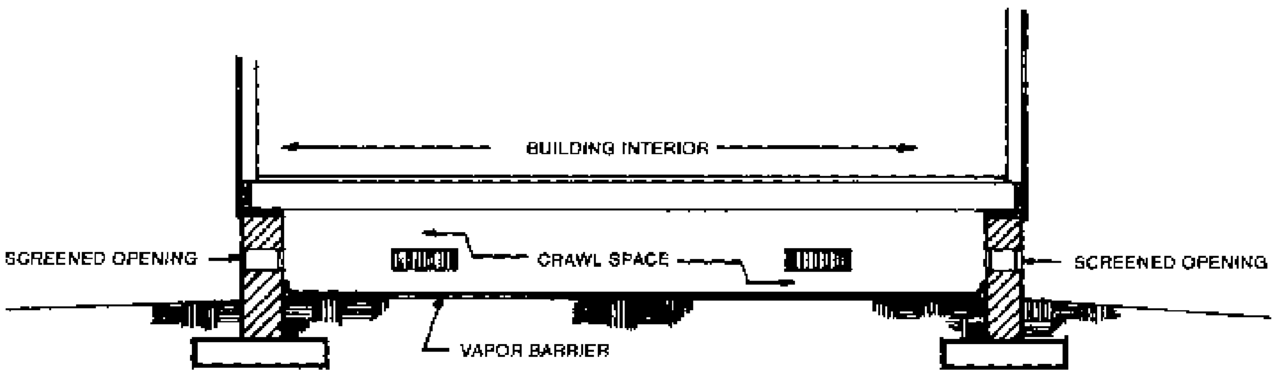


Figure 2-19. VENTILATED CRAWL SPACE.

2.4.3 Control of Wood Decay

2.4.3.1 *General.* Decay in wood is produced by organisms known as fungi, which live on wood components. All "dry rot" or "natural deterioration" of wood is caused by living fungi. The term "dry rot" is misleading as fungus cannot live without a regular supply of moisture. All decay destruction can be prevented. Wood-destroying fungi require favorable conditions of moisture, temperature, and access to air. Lack of any one of these essential conditions will inhibit the growth of fungi. Wood presents no decay potential if it has less than a critical moisture content, is maintained at extremely high or low temperatures, or is immersed in water or coated to exclude oxygen. Warm, humid climates or seasonal periods of high humidity provide an environment for growth of wood-destroying fungi. Frequent soaking of wood members, coupled with inadequate ventilation, may produce conditions suitable for fungi growth. Unpainted or untreated wood members, particularly those which touch the ground, are especially susceptible to decay. Some major areas susceptible to fungus attack are wood in contact with masonry foundations, cold-water pipes, or air-conditioning ducts; wood floors laid over concrete without adequate damp-proofing; wood in attics or crawl spaces with inadequate ventilation; all untreated wood in crawl spaces with standing water; lack of flashing around wall openings; wood porches, steps, columns, or posts in contact with the ground, and wooden door and window frames. The presence of decay is usually indicated by one or more of the following conditions: dampness and a musty smell; warped flooring and siding; surface cracks, particularly across the grain; fine, reddish-brown, dusty powder under the building; mildew stains on timbers; a hollow or spongy sound when timber is tapped with a hammer, or when a sharp-pointed tool easily penetrates timber; peeling paint; and swelling joints. Results of decay is illustrated in figure 2-20. If the presence of wood rotting is suspected, contact the pest control shop.

2.4.3.2 *Prevention of Decay.* The best procedure in preventing decay in untreated wood is to keep the wood dry. Air-dried wood does not contain enough moisture to permit the growth of wood-destroying fungi. At moisture content below the fiber saturation point (25 to 30 percent), decay is greatly retarded; below 20 percent, fungus growth is completely inhibited. Wood products used under adverse conditions must have a preservative treatment. Decay can be prevented by eliminating thecauses. Outlined below are a few of the steps which may be taken to accomplish this goal:

a. Provide a protective seal coat to prevent soaking of the wood.

b. Seal glass settings with putty and paint.

c. Provide tight caulking around wall openings.

d. Seal checked lumber, knots, and joints with putty and paint.

e. Before assembly, paint the back of all lumber that will not be accessible after assembly, such as window trim, porch decking, and doorheads.

f. Provide adequate maintenance and periodic cleaning of rainwater conductors.

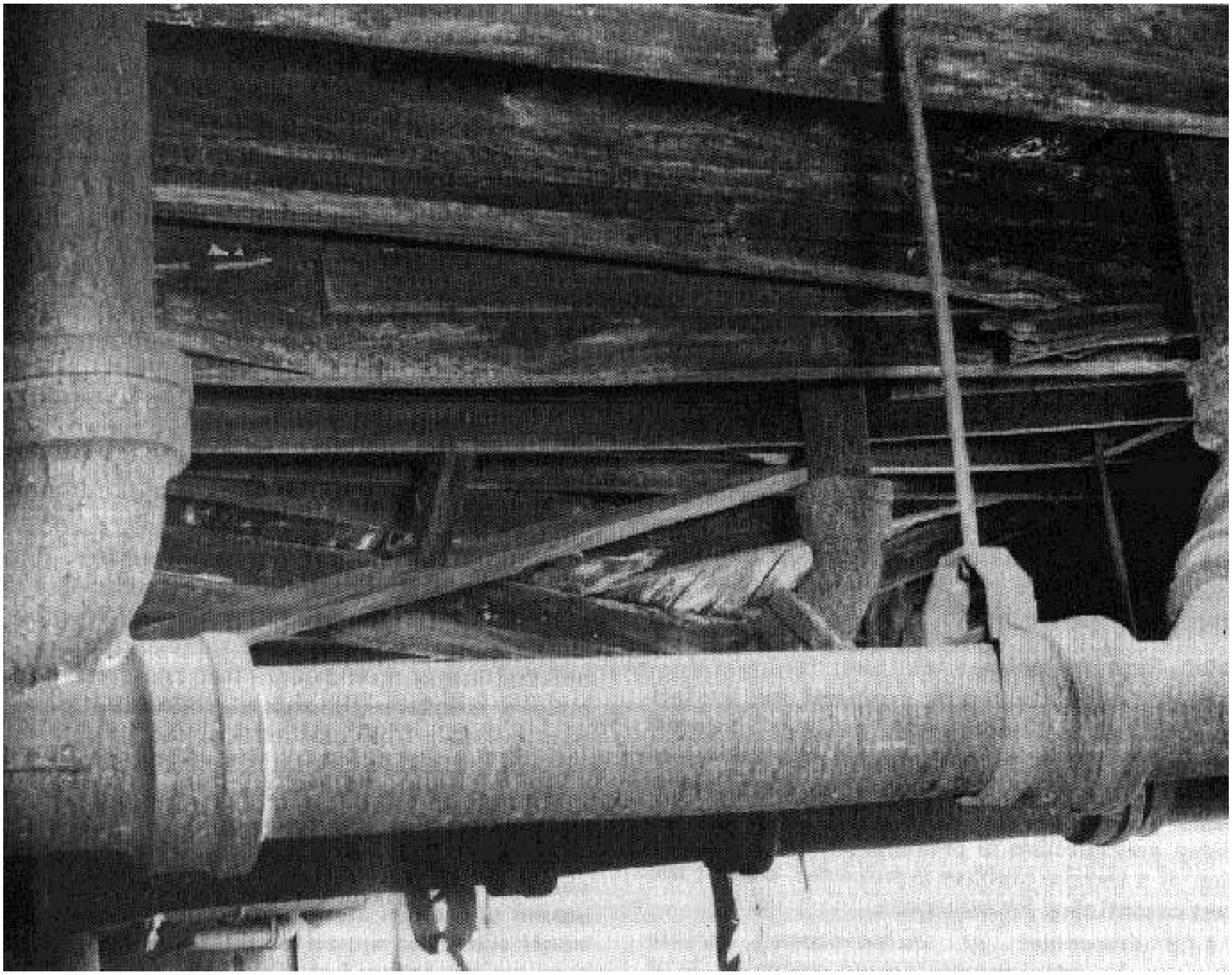


Figure 2-20. CRAWL SPACE DECAY.

g. Separate all wood from earth by resting it above the ground line on solid masonry blocks and vapor barriers.

h. Keep earth and debris away from wood, and slope the earth to drain away from walls.

i. Avoid trapping water on sills by cutting scuppers in the bottom rails of screen frame and screen doors.

j. Keep crawl space clear of debris.

2.4.3.3 *Treatment of Decay.* Upon the detection of decay, prompt action will be taken to determine the extent of damage and the probable causes. If structural members are involved, the advice of an engineer should be obtained to determine the materials and methods to be used in effecting the repair. The infected member may be removed and replaced with a member treated with a wood preservative (see Tri-Services Manual, "Military Entomology Operations Handbook," [TM 5-632, NAVFAC MO-310, AFM 91-16] chapter 8, section 5). Normally, the cause will be traced to excessive moisture or poor ventilation. Provision for the exclusion of moisture and provisions for adequate ventilation should be included as part of the repair. The wood area adjacent to the infected part should be treated to insure against possible spread of the fungus.

2.4.3.4 *Carpenter Ants.* Some insects such as carpenter ants are common in decayed wood. Once the cause for the decay is eliminated, the insect problem disappears but the damage caused by the insect may require repair.

2.4.4 Termite Control

2.4.4.1 *General.* Insects as a general rule are not a major maintenance or repair problem. However, termites are the one exception and constitute a serious problem in areas of infestation. Fortunately, some of the precautions effective against wood decay are, effective in preventing termite infestation. If a termite problem is suspected, contact the pest control shop for assistance.

2.4.4.2 *Prevention of Subterranean Termite Damage.* In subterranean termite control, it is of prime importance to keep untreated wood dry, well ventilated, and removed from contact with the ground. Termites must maintain contact or passage to and from the ground. Mechanical barriers, soil poisoning, and preservative treatment of timber are the major means of combating this menace. Mechanical barriers usually are in the form of termite shields. Unfortunately, unless these shields are properly installed and continually maintained, they provide little or no termite protection. Soil poisoning, also called chemical soil barrier (see Tri-Services Manual, "Military Entomology Operations Handbook," chapter 8, paragraph 8.15.1(8)) offers better protection at a reasonable cost. Chemical solutions are mixed with soil adjacent to foundation walls, piers and under concrete slabs (structures with subslab or intraslab heating/cooling duct shall not be treated until the vents are sealed and the system is reducted away from the soil). This provides long-lasting barriers to termites. Wood installed in suspect or susceptible areas should be pressure impregnated with a wood preservative.

2.4.4.3 *Treatment of Termite Damage.* The treatment of termite damage is similar to treatment of decay. The damaged members are removed and replaced with lumber that has been treated with a wood preservative. The assistance of an engineer may be needed if structural members are involved. Construction to prevent the recurrence of the termite infestation will be part of the repair.

2.4.5 Ventilation.

Adequate ventilation of enclosed crawl spaces is necessary to prevent decay resulting from condensation.

2.4.5.1 *Standards.* Standard guides for meeting ventilation requirements include:

a. For buildings up to 5,000 square feet. Determine linear footage of building perimeter and provide 2 square feet of ventilation per each 100 linear feet. Additionally, determine the total crawl-space ground area and provide ventilation at the rate of **a** of 1 percent (0.0033) of the total crawl space ground area. Example: Assume a building size of 4,000 square feet and assume the building is square-the square root of 4,000 square feet is 63.245. This multiplied by the number of sides in the building yields 253 linear feet, or 2.53 when divided by 100. 2.53 x 2 (the number of square feet of ventilation required for each 100 linear feet) yields 5.06 square feet of ventilation required for the perimeter of the building. In the second portion of the equation, crawl-space area would equal the square footage area of the building, or 4,000 square feet. This multipled by **a** of 1 percent (0.0033) yields 13.2 square feet of ventilation required. Combining the two yields, 5.06 and 13.2, 18.26 square feet of ventilation would be required for a building size of 4,000 square feet.

b. For buildings larger than 5,000 square feet, determine the linear footage of the perimeter and provide 2 square feet of ventilation for each 100 linear feet. Additionally, determine the total crawl-space ground area and provide ventilation at the rate of ¼ of 1 percent (0.0025) of the total crawl space ground area. Using the procedures in the above example, and assuming a 6,000-square. foot building, 21.2 square feet of ventilation would be required for this building.

c. For interior foundation walls, ventilation is required at the rate of 1 square foot per each 25 linear feet of foundation with the requirement for cross ventilation.

The above requirements may be reduced in arid or semiarid climates. In severely cold temperature zones, operable louvered vents should be closed during the cold season. Vents shall remain open in temperate and tropical zones or zones with high humidity.

2.4.5.2 *Installations.* Crawl spaces may be ventilated by the installation of gratings or louvers of an adequate size in the foundation walls. Small round louvers, which can be installed by drilling with an expansion bit and tapping into place, are commercially available. Vents through interior walls are equally important. Both types of vents should be installed to insure free air circulation throughout all parts of the underfloor space.

2.4.6 Coordination with Entomology Service

Close cooperation between the maintenance service and the entomology service must be maintained in areas of mutual interest. Maintenance personnel should be instructed by the entomology service in recognition and detection of wood decay fungi and termites. This will enable craftsmen to recognize signs of an early fungus attack and to differentiate between the fungus damage and the destructive effects of moisture and weathering. It is advisable to make this recognition and detection part of the inspection checklist where wood structures are concerned. Joint inspections by both services are encouraged. Investigation of damaged areas, determination of probable cause for damage, and agreement on types of repairs are joint functions. Understanding and appreciation of mutual problems will foster a spirit of cooperation, which will improve the overall effectiveness of both services.